Investigating the use of behavioural, accelerometer and heart rate measurements to predict calving in dairy cows

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Abstract

Calving is an essential event in dairy production, as lactation only begins after calving and cows must give birth at regular intervals in order to maintain milk production. Careful management is important during the weeks around calving as this is when dairy cows most frequently experience health problems. Experienced stockmen use judgements based on physical and behavioural changes in order to recognise when cows may be about to calve, and subsequently be available to offer assistance when required. With increasing herd sizes and large numbers of cows per stockman, individual attention is often difficult. An automated system that monitors behavioural or physiological changes before calving could potentially be used to predict the time of calving, and help improve supervision by farm staff.

Data comprising two years of records from Langhill Farm were used to identify any variables which could be used for calving prediction or as risk factors for various calving problems. Records kept by stockmen detailing the signs of calving and time of observation were compared with quantitative behavioural data.

Observations from video recordings were used to identify any consistent behavioural changes occurring the day before calving that could be used to predict the onset of calving. The frequencies of lying and tail raises proved to be the most useful indicators, as they showed consistent changes in the final six hours before calving. Differences between heifers and cows, and between those experiencing calving difficulties and those which did not, were also investigated. Differences between heifers and cows were shown which should be taken into account when predicting calving times. However, no early-warning signs of difficulties were identified for cows and heifers assisted with a calving jack.

Cows were also fitted with collars containing accelerometers to investigate if features in tri-axial accelerometer data could be shown to correspond to specific behaviours.

Some success was achieved in identifying eating behaviour and postural changes, demonstrating that there is potential for monitoring behaviour using this method.

Weekly heart rate recordings were also taken to establish if there was a change in the heart rate or heart rate variability during the final six weeks of gestation. Changes were found but, although they were statistically significant, they were considered too subtle for any practical application.

Consistent changes in behaviour were observed in the six hours before calving, some of which could be measured using accelerometers. These changes have the potential to be used as the basis of an automated monitoring system to predict calving.

Declaration

I hereby declare that this thesis is of my own composition and that all assistance has been duly acknowledged. The results presented herein have not been previously submitted for any other degree or qualification.

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Contents

Chapter 1: Introduction

Calving is an extremely important event in the life of a dairy cow. This marks the beginning of lactation and is therefore an economically significant event. Female calves are also essential to provide replacements for the dairy herd. However, the time around calving is also when dairy cows are most vulnerable to clinical disorders, and calving problems are also very common. Modern dairy cows have been highly selected to produce high milk yields. With the focus on increased production for a number of years there has been a corresponding increase in the number of physical and physiological problems faced by dairy cows (Mottram, 1997).

During the transition period, normally defined as from three weeks before until three weeks after calving, cows are vulnerable to metabolic disorders such as milk fever, ketosis, metritis, mastitis and displaced abomasum (Drackley, 1999; Huzzey *et al.*, 2005). Milk fever and most other production diseases occur most frequently in the 30 days following parturition. For example, in one study, 96% of milk fever cases were recorded during this time (van Dorp *et al.*, 1999). Milk fever is exacerbated by the voluntary reduction in feed intake before calving and high milk yields in the very early stages of lactation. This is primarily a disorder of dairy cows and is extremely rare in beef cattle (Phillips, 2001).

Calving difficulties are also becoming increasingly common with many dairy cows requiring assistance at the time of calving (Mee, 2008). To maximise welfare and minimise losses due to calving problems, all animals need to be individually monitored to identify any calving difficulties or health problems as early as possible. Even if cows are checked regularly, it can be difficult to assess (from visual observation alone) exactly how close a cow is to calving, so it is easy for problems to go undetected for some time. Similarly, the practice of group monitoring of dry matter intake and milk production for the identification of problems is likely to miss changes in individual cows (Cook and Nordlund, 2004). Improved monitoring during the transition period would help minimise losses and consequently improve the health and welfare of cattle.

At the same time that health and welfare problems in dairy cattle are increasing, the number of cows per farm is also increasing across Europe, resulting in a rise in the number of animals that each stockperson is responsible for. This means less time is available for the management of each individual cow and there is an increasing need for automatic systems to help with livestock management (Raussi, 2003). Automated systems are becoming more widely used for milking, feeding and detecting oestrus in dairy cows, and new technology is being developed in the area of health monitoring. According to a review by Mottram (1997), parturition is amongst the most suitable events for routine monitoring.

Behaviour can be monitored non-invasively and accelerometers are increasingly used in studies of animal behaviour to supplement or replace monitoring by direct or indirect observation. This technology could be applied to measure the behaviour of dairy cows for the purpose of predicting calving and any associated problems.

1.1 Management of production in dairy cows

Female dairy calves are known as heifers and begin their productive life after their first parturition, when they become cows. This is the point when lactation begins and they are introduced into the milking herd. Dairy heifers in the UK are normally inseminated when they are around 15 months old, so that they will give birth when they are roughly two years of age (Wathes *et al.*, 2008). Calving for the first time at or near 24 months of age provides the overall highest lifetime yield and profitability (Hoffman and Funk, 1992).

In cows, milk yield increases rapidly to a peak after about 4-5 weeks during early lactation and then decreases gradually during mid-lactation before drying off (Phillips, 2001). Heifers produce a relatively constant milk yield during their first lactation, but older cows have a more pronounced lactation curve (Figure 1.01).

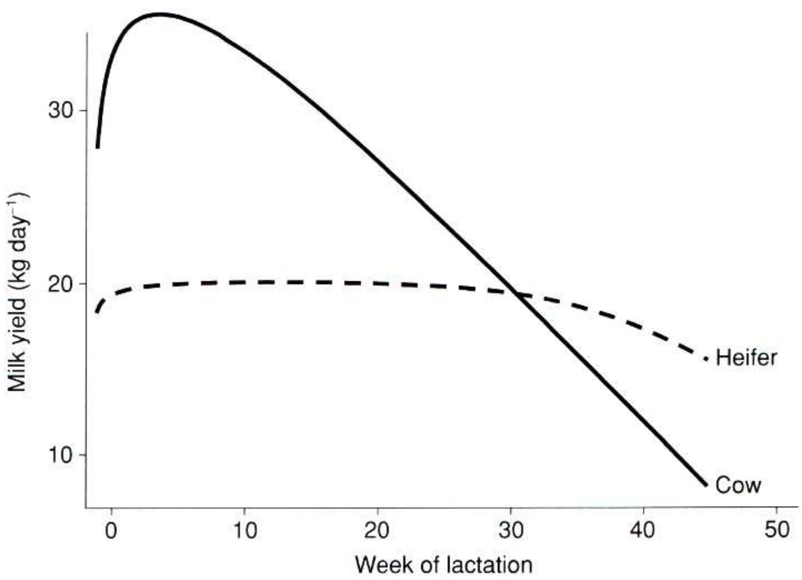

Figure 1.01
The generalised lactation curves of a cow and a heifer. The milk yield of cows rises quickly for the first 4-5 weeks of lactation and then falls gradually, whereas heifers produce a more constant milk yield throughout lactation (Phillips, 2001).

This difference in production levels between heifers and cows is one difference between individuals at different stages of development which may affect the management required for each age category (Houwing *et al.*, 1990).

Milking will normally continue for an average of 305 days, after which cows are dried off in preparation for the birth of their next calf. This dry period lasts an average of 60 days. This allows cows to rest before they calve and gives time for the udder to regenerate and repair. Dry cows are usually kept in two groups, a far-off group and a close-up group. This close-up group includes those cows which are due to calve within three weeks (Hulsen, 2006). This close-up group includes cows that have entered the transition period (three weeks before until three weeks after calving). This is a very important time for dairy cow management, when cows are especially vulnerable to a number of disorders and many complications can occur (Drackley, 1999). The exact durations of these milking and dry periods will vary depending on the management on the farm but these figures are based on an average calving interval of 365 days, which is the target of most UK farms. Under this system there is a period of about 80 days from when a cow calves until she next conceives, so that she is pregnant for much of her lactation. The average productive lifespan of a dairy cow in the UK is three lactations (Compassion in World Farming, 2009). The whole life cycle of a dairy cow (up to culling) is illustrated in Figure 1.02.

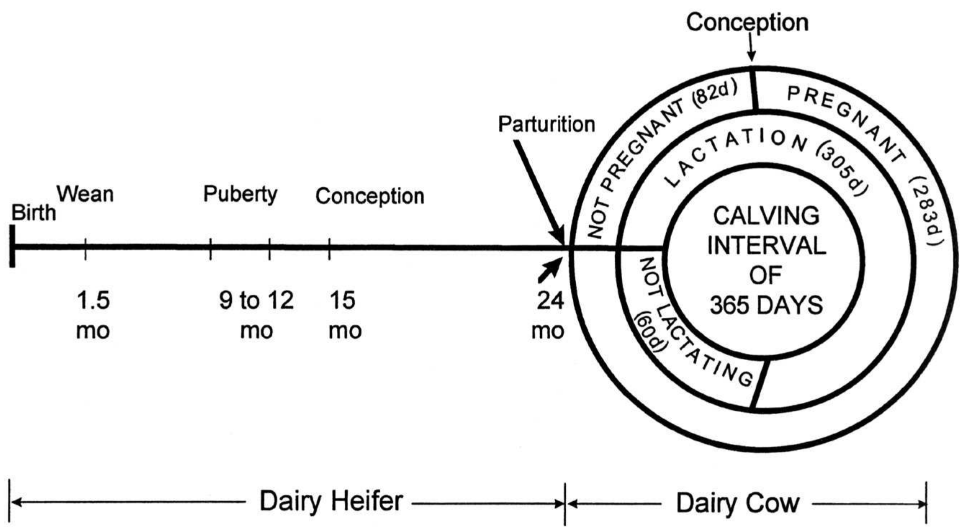

Figure 1.02
The life cycle of a dairy heifer from birth until lactation, followed by the annual life cycle of a dairy cow, based on a 365 day calving interval (from Knobil and Neill, 1998).

1.2 Physical changes before calving and the stages of parturition

Experienced stockmen use judgements based on physical and behavioural changes to recognise when a cow may be about to calve. External signs can often be observed before calving and are used by stockmen for prediction.

Perhaps the most reliable sign for predicting the time of calving is the relaxation of the pelvic ligaments. Once these are fully relaxed, the cow usually calves within 24 hours (Hulsen, 2006). This can be measured subjectively with relatively high success. In a study of 23 Holstein-Friesian dams (nine of which were heifers) the time of birth could be predicted to be in the next 22 hours on the basis of the relaxation of the broad pelvic ligaments in 52.5% of cases (Birgel *et al.*, 1994). However, when this is measured objectively, the accuracy of prediction can be greatly increased. Shah *et al.* (2006) measured the relaxation of the pelvic ligament using two scales (one firmly held parallel to the ligament, between the sacrum and tuber ischii, and the other erected perpendicular to the first with the bottom end just touching the ligament, measured at the point where it touched the first scale). A gradual increase in relaxation was observed from day 100 of gestation until two days before calving. Then a much larger increase of 31 ± 2 (S.E.) mm was measured the day before calving. An increment of 5 mm or more from the preceding day was successfully used to predict calving within 24 hours in 31 of 37 cows.

Around the same time that the ligaments slacken, the cervix also begins to dilate. This is not visible externally but can be measured by calculating the distance between two ultrasound transducers placed opposite each other on the external rim of the cervix. Breeveld-Dwarkasing *et al.* (2002) used this method to study cervical dilation during five induced calvings. Four phases of dilation were described, starting with the latent phase during which there was no increase in dilation. This was followed by an acceleration phase, lasting 4.3-6.8 hours, during which dilation rate speeded up until reaching the third phase. This was the phase of maximum slope, when dilation increased at an even higher rate for 0.5-4.8 hours. The final phase shows deceleration of the rate of cervical dilation. This is an interesting method for investigating the process of calving under controlled experimental conditions but such invasive methods would be challenging to apply in a practical manner without veterinary assistance.

Another sign which can be observed visually is the swelling of the udder when it fills up with milk, known as "bagging up" (Phillips, 2002; Hulsen, 2006). There is also a change in the mammary secretion from a relatively transparent, honey-like secretion to colostrum which is opaque in appearance and less viscous (Dufty, 1971; Noakes *et al.*, 2001). Changes in the udder are often quoted as a sign of calving but the accuracy with which they can be used to predict the precise time of calving is questionable. In a study of Swedish dairy cattle, enlargement of the udder was seen earlier in heifers than in cows and was among the most reliable and useful signs for predicting calving within the 12 hours after inspection (Berglund *et al.*, 1987). A more recent study of 105 beef cows of mixed parities measured mammary development, mammary swelling and swelling of the fore-udder every eight hours for the last seven days before calving. The proportion of cows that showed changes increased as calving approached but this could not be used to predict the time of calving within the final seven days before calving (Sendag *et al.*, 2008).

Swelling of the vulva is another physical change that can be observed before calving (Phillips, 2002; Hulsen, 2006). The size of the vulva increases slightly in both vertical and horizontal dimensions, while the lips gradually soften and become more mobile (Dufty, 1971). Wide variation was found between cows in both the onset and progression of external signs of calving in a study of Swedish dairy cattle. When various signs were analysed for their value for predicting that calving would occur within the next 12 hours after inspection, swelling of the vulva was less useful than observations of udder distension and relaxation of the pelvic ligaments (Berglund *et al.*, 1987). Similar results were found in a study of beef cattle that measured the extent of vulval swelling, discharge from the rima vulvae, and the colour of the mucous membranes in the vaginal vestibule during the final week before parturition. Swelling of the vulva was observed in all animals and the proportion of animals that this was observed in increased closer to parturition. This sign was considered to be most closely related to the time of calving but was not suitable for more precise determination of the time of parturition (Hofmann *et al.*, 2006). An increase in the volume of vaginal secretions was also described by Dufty (1971) but this was not observed in many individuals (only 4 of 44 cows).

One large physical change between the first and later calvings is seen in the structure of the uterus, which is larger and thicker in older individuals (Noakes *et al.*, 2001). This cannot be observed externally but may contribute to differences in the physiology and behaviour of cows of different parities.

Parturition can be described with three stages of labour. The first, preparatory stage, describes when the structure of the cervix changes to allow it to dilate and the pelvic ligaments slacken (Ball and Peters, 2004). This is also the time when the foetus extends its extremities in preparation for expulsion. Myometrial contractions also begin at during this time, although these are not visible externally (Noakes *et al.*, 2001). This stage ends when the water bag ruptures and the calf's hooves are seen (Phillips, 2002). The birth site is often determined by where the water bag bursts because cows are highly attracted to the fluids around the time of calving and usually remain at the site, often licking or pawing the ground (Hafez and Hafez, 2000). There is a lot of variation in the duration of this stage, which can last just over two hours (Phillips, 2002) or as long as six to 24 hours. This stage, and the whole birth, tends to be shorter for older cows (Ball and Peters, 2004). Tail raising and waving are common during this stage, usually for longer than two minutes each time (Phillips, 2002).

The second stage of parturition involves the delivery of the calf through the pelvic canal (Ball and Peters, 2004). The calf is forced through the birth canal during strong abdominal straining which contracts the diaphragm behind it. The straining coincides with uterine contractions at regular intervals of 15-20 minutes. Each of these uterine contractions is associated with 8-10 abdominal contractions. These are coordinated as uterine contractions force the foetus into the pelvic inlet, which activates the pelvic reflex and stimulates straining (Noakes *et al.*, 2001). The cow may stand initially during this stage but will normally lie laterally with her legs outstretched when the head and shoulders of the calf are expelled. The critical point is the expulsion of the head, after which the rest of the body normally follows quickly. There are no further contractions after the hips are expelled and the hind limbs are only freed when the calf moves or the dam stands up (Noakes *et al.*, 2001). This stage is usually completed in about an hour (Phillips, 2002) but this can range from 30 minutes up to as long as four hours (Ball and Peters, 2004). If a cow is frequently disturbed, she will stand which can delay labour (Phillips, 2002). This stage of parturition tends to be longer in heifers than in multiparous cows. In beef cattle, average durations of 54.1 minutes and 22.5 minutes for heifers and cows, respectively, have been reported (Doornbos *et al.*, 1984). One monitoring device has been developed that uses the opening of the vulva as the trigger for an alert that parturition is in progress. This entails a device that is sutured on either side of the vulva and detects when it opens for the expulsion of the foetus. This was originally developed for use with mares, but is reported to be effective for a number of species, including cows, sheep and llamas (Foalert, 2009).

The third and final stage of the parturition process describes the time from the birth of the calf until the placenta is expelled. This normally takes from two to six hours (von Keyserlingk and Weary, 2007). There is likely to be a pathological cause if the placenta is not expelled within 24 hours of the birth (Ball and Peters, 2004).

1.3 Behavioural changes during gestation and parturition

A number of studies have been conducted on the behaviour of cows before and during parturition, covering a range of behaviours and durations of study, but mainly within the final days before calving. Only one study did not report any change in behaviour prior to parturition. Lidfors *et al.* (1994) used instantaneous time sampling to monitor cows from five days before calving. Samples were recorded every five minutes for 30 minutes, four times daily. This corresponds to only 28 samples recorded during two hours each day which may not be sufficient data to capture the changes observed by other researchers.

In a similar manner to some of the physical changes, the behaviour of cows shows gradual changes throughout gestation and then more obvious, short-term changes in the last few days before parturition. One change in behaviour that is directly related to physical change is the gradual reduction in dry matter intake during the dry period as the increasing volume of the uterus limits the space available for food (Jordan *et al.*, 1973; Hulsen, 2006).The decrease in feed intake is also accompanied by a decrease in time spent ruminating. Bao and Giller (1991) recorded behaviour at 30-minute intervals for 24 hours, once a week for the last seven weeks of pregnancy and found a regular decline in feeding and rumination from at least three weeks before calving. It has been suggested that cows eat less on the day of calving because of the calving process and the associated stress. This stress can be due to social conflicts, deficiencies in housing and dietary changes during the dry period. Dry matter intake on the day of calving is a good indicator of the quality of dry cow management, as cows that eat more on the day of calving will get a better start to their lactation (Hulsen, 2006).

Decreases in feed intake before calving may also affect the water intake of cows. The time spent drinking increased from an average of 5.5 minutes a day before calving to 6.8 minutes a day after calving (Huzzey *et al.*, 2005).

Changes in social behaviour also begin from around six weeks before calving. From around this time, cows will avoid aggressive interactions to protect their foetus and become increasingly reluctant to engage in social encounters by feeding by herself or at the edge of the herd (Phillips, 2002). However, normal pre-parturient behaviour such as this may not always be possible under intensive housing conditions (Fraser, 1985).

An increase in restlessness can begin from as early as 1-2 weeks before calving, before intensifying in the last few days. Restless behaviour includes regular looking and turning around, vocalisation, licking and pawing bedding material, tail lifting and waving, increased mobility, separation from herd, frequent alternation of lying and standing, and interrupted eating patterns (Lidfors *et al.*, 1994; Phillips, 2002). This change in eating patterns was studied by Ruckebusch (1975) who used an automated system to record the jaw movements of two cows and found that they fed only during the daytime and in shorter bouts for the week before calving.

The anecdotal reports of interrupted lying bouts associated with restlessness before calving have also been studied quantitatively. One study recorded the time when restlessness was observed as around 140 minutes before calving (Owens *et al.*, 1985). Huzzey *et al.* (2005) used automated devices to record standing and found an increased number of standing bouts (defined as the interval between two lying events) on the day of calving, with an average of 21.8 bouts at calving compared with 11.7 bouts the day before and 13.1 bouts the day after. This increase was believed to be caused by the discomfort associated with the regular myometrial contractions which made cows restless at the onset of the first stage of parturition (Fraser, 1985). Another possible explanation for restless behaviour may be that the dam is looking for a suitable calving site. As a hider species, cows prefer to calve in a concealed site and may separate from the rest of the herd before calving, if they are able to (Broom and Fraser, 2007). A lack of suitably concealed, undisturbed places to calve may increase restlessness and delay the onset of calving, although this has never been investigated.

The behaviours observed during the first stage of parturition vary between primiparous heifers and multiparous cows and between normal and difficult births. Wehrend *et al.* (2006) used one-zero recording to score a number of behaviours during the first stage of labour. With this method of recording, the observer scores whether or not each behaviour occurs during a defined sampling period (Martin and Bateson, 2007). Each individual was also subjectively classified as calm, restless or very restless. The study included 10 heifers and 68 cows without dystocia, and nine cows with dystocia. None of the heifers were scored as calm, but 32% of the multiparous cows were. The other difference observed between heifers and cows was that a higher proportion of heifers (80%) pawed with their forefeet than cows (34%). Higher proportions of cows with dystocia were found to rub against walls (89% compared with 34%), discharge urine (78% compared with 25%), and scrape the floor (89% compared with 24%) compared with the proportions seen in cows with no problems. These results are useful to identify behaviours which are observed at this stage of calving but the study did not provide any information regarding the durations or frequencies of behaviour.

All of the cows and heifers observed by Wehrend *et al.* (2006) extended their tail during the first stage of parturition, and this is a behaviour that is strongly associated with calving. This behaviour was used as the basis for an automated device to predict parturition in cows and mares using a tail sensor (Bueno *et al.*, 1981). The device was attached around the tail and held on with straps (Figure 1.03).

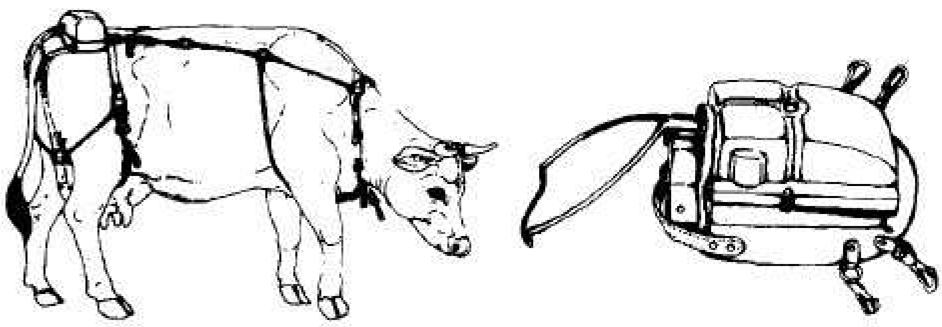

Figure 1.03
The attachment of a tail sensor to predict calving from extended durations of tail raising (Bueno *et al.*, 1981).

More tail movements lasting longer than two minutes were recorded at the time of parturition, but also occasionally from two to five days earlier. Tail movements shorter than four minutes were believed to be related to foetal kinesis or uterine contractions rather than parturition.

The first stage of parturition ends when the water bag bursts, after which the dam usually stands and licks the birth fluids. Pinheiro Machado *et al.* (1997) investigated the timing of the attraction to amniotic fluid and found that it started about 12 hours before calving. This is also the time when pre-parturient maternal interest is expressed and females show interest in recently-born young of other females shortly before parturition. This early onset of maternal behaviour is likely to be triggered by early changes in hormone levels and can occasionally result in calf-stealing (Fraser, 1985). Sniffing and licking of alien calves during the last few hours before birth has also been observed in beef cattle (Lidfors *et al.*, 1994).

Both restlessness and ground licking can be observed using video camera systems to monitor cows around the time of calving. Various cameras are available for this purpose and are marketed as an effective tool to assist with transition cow management (Allen Leigh Security and Communications, 2009; Equicom CCTV, 2009). An advancement of this technology is being developed by Cangar *et al.* (2008) who used online image analysis to automatically monitor the locomotion and posture of cows prior to calving. This technique, that works in real-time, allows changes in locomotion and posture to be identified from video surveillance images and has the advantage of being relatively cheap and non-invasive. Image analysis was used to classify the behaviour of eight cows for 24 hours before calving. On average, 85% of standing and lying and 87% of eating and drinking were classified correctly. The authors recognised the need for further validation and investigation of the behavioural changes which may indicate calving but this could potentially be a very useful technique.

Automated postural measurements are easier for animals housed in enclosed spaces, such as sows in farrowing crates. Transitions between lying and standing can be measured fairly accurately using ultrasonic measurements. The sows show a distinct increase in postural transitions before farrowing so this system was able to predict farrowing within three hours in 32 sows, with 75% accuracy (Wang *et al.*, 2005; Wang *et al.*, 2007).

Relatively simple measures of behaviour are also able to predict lambing in free-ranging Mouflon ewes. Collars containing accelerometers were used to continuously sample behaviour and summarise activity over 15-minute or 30-minute intervals. This was then used to calculate the number of hours spent active each day, which decreased for 3-5 consecutive days around lambing. This method was able to classify lambing behaviour with 93% accuracy (Langbein *et al.*, 1998a; Langbein *et al.*, 1998b).

Similar approaches have as yet been less successful at identifying parturient behaviour in cows. Using a sensor attached to a leg to detect standing, walking and lying, an algorithm was developed based on the behaviour of 15 cows before calving. The model was based on activity, lying time (% of 24 hours), lying bouts and restlessness, and was used to predict calving within the next 24 hours in a sample of 12 cows, with 10 true positive results. There were major differences between individuals and a number of false positive results (Maltz and Antler, 2007).

Cattle vocalise relatively rarely but 64.1% of cows with no problems at calving have been observed to vocalise during the first stage of parturition (Wehrend *et al.*, 2006). In studies of cows in slaughter plants, vocalisations generally occurred immediately after stressful events such as electric prodding, slipping, missed stuns or excessive pressure during restraint (Grandin, 1998; Grandin, 2001). Vocalisation is also seen in both dams and their calves following separation (Marchant-Forde *et al.*, 2002) and in 16.2% of isolated steers (Watts and Stookey, 2001). In a study comparing vocalisations of cows that were branded and those that were not, more of the branded cows vocalise during restraint and the acoustic parameters also varied between the two treatments (Watts and Stookey, 1999). Although the vocalisations of cattle are not well understood, these observations suggest that they indicate unpleasant sensory or emotional experiences. Watts and Stookey (2000) have reviewed the literature on vocalisation in cows and emphasised the potential significance of the conditions under which cows vocalise. Vocal responses are suitable for more detailed investigation as they can be recorded non-invasively and analysed using fairly simple equipment.

Most cows lie laterally when the calf is expelled at the end of the second stage of parturition (Houwing *et al.*, 1990). This is a sign used in automated systems to predict foaling in horses. Lateral recumbence is an uncommon posture for horses, so can be used as a fairly reliable indicator of parturition (Wessel, 2005).

The tendency in the research work to date is for detailed studies to be conducted on a specific behaviour, or group of behaviours. Longer trials have been conducted with the use of automatic recording systems but the behaviours that can be measured this way are limited to eating, drinking, standing and lying. In the case where all behaviours that are specific to calving were recorded, only their presence or absence was noted. Detailed behaviour during the 24 hours before calving has not been previously recorded. This could be used to identify behaviours that are indicative of parturition and assess if calving could be monitored using an automated system that was able to recognise relevant behavioural changes.

The range of research conducted in other studies shows the variation in the levels of analysis which exist when studying behaviour, from complex social interactions between individuals to details of the movements of each individual. Each method reflects the questions that are asked in each study (Martin and Bateson, 2007). The existing research literature on behaviour before calving is summarised in Table 1.01.

Table 1.01 Summary of publications on the behaviour of cows before and during parturition, listed in order of time before parturition studied

Time before parturition	Sampling and recording rules (sample size)	Recording method	Behaviours recorded + main results	Reference
7 weeks (once per wk)	Instantaneous time sampling 30-min interval for 24 h (n=44)	Observer present	Feeding, ruminating, lying, standing - regular decline in feeding, rumination and food intake from 3 weeks before parturition	Bao & Giller, 1991
23-27 d	Continuous focal observation (n=101)	Automated + Video recordings	Feeding, drinking, intake, body condition score, calving difficulty, milk yield - decreased feeding time and DMI before	Huzzey *et al.*, 2007
2 weeks	Continuous focal observation (n=2)	Automated	Jaw movements, sleeping - only ate during the day and ruminated in shorter bouts in week before	Ruckebusch, 1975
10 d	Continuous focal observation (n=15)	Automated + Video recordings	Feeding, drinking, standing - increased number of standing bouts on day of calving	Huzzey *et al.*, 2005
5-10d	Continuous focal observation (n=15)	Automated tail sensor	Tail raising (frequency and duration) - longer tail raises before calving	Bueno *et al.*,1981
5 d	Instantaneous time sampling 5-min interval for 30-min, 4×daily (n=14)	Observer present	Standing/walking/lying. Browsing/eating hay/ruminating - no significant changes	Lidfors *et al.*, 1994
1 d	Continuous focal observation (n=23)	Video recordings	Standing, lying, calving difficulty score, calving duration - cow standing and lying behaviour differed on day of calving	Misch *et al.*, 2006
12 h	Instantaneous time sampling 5-min intervals (n=30)	Video recordings	Lateral/semi-lateral lying, standing, walking Eating/drinking/ruminating/licking objects/self-licking - standing decreased in last 3 h, decline in rumination during 12 h before	Houwing *et al.*, 1990
From first signs of calving	Continuous *ad libitum* sampling (n=49)	Observer present	Restless behaviour, beginning of contractions, appearance and rupture of water bag, appearance of calf, time of birth - restlessness occurred about 140 min before birth	Owens *et al.*, 1985
First stage of labour only	Qualitative scale of restlessness One-zero recording of behaviours (n=87)	Observer present	1. Calm, 2. Restless, 3. Very restless Exploratory behaviour, olfactory ground check, nest-building, lying down and getting up, extending tail downward, scraping floor, tail-swishing, looking back at abdomen, hunching back, pawing, vocalisation, intake of amniotic fluid and feed, drinking, rumination, discharge of urine + faeces, grooming, rubbing against wall - differences between cows and heifers; normal and dystocic calvings	Wehrend *et al.*, 2006
48, 24, 12, 6 h before expected	Continuous focal observation; pref. testing; silage or silage + placenta /amniotic fluid (n=13)	Observer present	Inspecting troughs, eating from troughs, not at troughs, care-giving to calf - attraction to amniotic fluid started before delivery (around 12 h before) - not attracted to placenta prior to parturition	Pinheiro Machado *et al.*, 1997

1.4 Physiological changes during gestation and parturition

Gestation is a time of considerable physical and physiological change. Substantial weight gain results from the enlargement of the uterus, mammary tissues, body fat reserves and foetal growth. There are also changes in the mechanical properties of bone and ligaments, and changes in cardiac function (Marchant-Forde and Marchant-Forde, 2004). The physiological response of the dam to the presence of the developing foetus and placenta involves complex changes in cardiac output and control. These include increases in cardiac output (stroke volume × heart rate) and blood volume. The pattern of change varies between species but the integrated cardiovascular response is fairly consistent. These changes in cardiac activity are normal and critically important for the growth and development of a healthy foetus. Cardiac output increases in response to the increased metabolic needs and rise in oxygen consumption. The most significant increase in oxygen demand is during the final trimester but the cardiovascular changes happen before this, within the first half of gestation (Knobil and Neill, 1998). The increase in cardiac function involves a complex interplay between the nervous system, circulating hormones, and structural and functional alterations within the heart, arteries and veins.

Increases in the average heart rate of dairy cows have been previously recorded during the last three months of gestation from 71.3 beats per minute, 31-40 days before calving, to 91.7 beats per minute, 1-10 days before calving (Thomas and Moore, 1951). Other features of heart rate and rhythm have also been found to change during gestation. Rezakhani *et al.* (2004) compared heart rates and other electrocardiogram features of pregnant and non-pregnant dairy cows. Pregnant cows had significantly higher P-wave amplitudes that may have been caused by the position of the heart being altered slightly by the distension of the abdominal cavity and slightly changing the recorded ECG signal. Pregnant cows also had shorter Q-T and T intervals, which are negatively correlated with heart rate so this is likely to be due to the higher heart rate recorded during gestation.

Parturition is a normal but complicated event regulated by many physiological and psychological factors. This event creates stress for both the dam and the foetus, and is recognised as a severe form of pain (Hydbring *et al.*, 1997). Following the gradual changes in cardiac function during gestation, heart rates often increase to 80-90 beats per minute during the first stage of parturition and then increase to 100 beats per minute or higher during the second stage of parturition (Noakes *et al.*, 2001).

There are a number of hormones that have important functions during gestation and at parturition. The endocrine changes associated with parturition are fairly well established but the factors that initiate birth and terminate gestation after a constant length of time are not completely understood. However, the current concept is that the foetus determines the length of gestation and the dam can influence the time of birth, within narrow limits (Noakes *et al.*, 2001). It has been shown that multiparous cows tend to avoid calving around milking time (Edwards, 1979), suggesting that the dam has some ability to delay calving until a time when she is less likely to be disturbed.

Foetal stress develops as the placenta is less able to support the growing demands of the foetus, causing an increase in the production of foetal cortisol (Jackson, 2004). During the final 20 days, there is also a 15-fold increase in the maternal plasma concentration of corticosteroids, which appears to be important for the initiation of parturition. An increase in the concentration of plasma cortisol induces the placenta to increase oestrogen production relative to progesterone (Ball and Peters, 2004).

Progesterone is produced by the corpus luteum in the ovary until this role is assumed by the placenta at between 150 and 200 days of gestation (Noakes *et al.*, 2001). This hormone is important for the maintenance of pregnancy and inhibits ovulation during gestation. Plasma concentrations of progesterone begin to decrease during the last 20 days of gestation, and then fall more rapidly in the final few days before parturition (Ball and Peters, 2004). If this change could be easily monitored, progesterone could potentially be used to predict calving. A study was conducted to evaluate an on-farm test for calving prediction from measuring blood progesterone. Daily blood samples were taken from five days before cows were due to calve. Tests were deemed to be negative if progesterone was high, and low concentrations were interpreted as a positive result for calving within the following 24 hours. Testing whole blood samples achieved a sensitivity of 80% with 98% specificity and a predictive value of 89%. Calving within 24 hours was predicted correctly for 49 of 52 cows using this test. More than 95% of the cows in this study calved within 24 hours of their plasma progesterone falling below 1.3 ng/ml making this a good predictor of calving (Matsas *et al.*, 1992). Another smaller study which also used a drop in progesterone levels (to below 1.5 ng/ml) to predict calving reported a similar successful prediction rate of 91% (Birgel *et al.*, 1994).

Oxytocin is a peptide hormone secreted by the posterior pituitary. The levels of this hormone remain fairly low during late gestation and the early stages of parturition but increase to reach a peak when the foetal head emerges from the vulva and when the foetal membranes are expelled. Oxytocin receptors increase during late gestation and oxytocin release is correlated with electromyographic activity of the uterus (Noakes *et al.*, 2001). A lot of research has been conducted on oxytocin in sheep at parturition and how this relates to maternal behaviour. In ewes, the release of oxytocin is stimulated by distension of the birth canal due to the expulsion of the foetus, which then accentuates the myometrial contractions (Meurisse *et al.*, 2005).

Oestrogens are steroid hormones produced by the ovary and placenta that are responsible for the function of female reproductive organs. The plasma concentrations of the oestrogens oestrone sulphate and oestradiol are correlated with the relaxation of the pelvic ligaments. The concentration of oestrone sulphate increases progressively until the day before calving and then decreases significantly. The concentration of oestradiol increases gradually from 100 days before calving until four days before, when it increases drastically to peak on the final day before calving. This marked change in oestradiol was 85% accurate for predicting calving within 24 hours in 23 of the 37 cows in a study by Shah *et al.* (2006), but this was less accurate than prediction from the measurement of the relaxation of the ligaments which was 93% accurate for 31 cows.

Relaxin is a peptide hormone produced by the corpus luteum and is involved in relaxation of the cervix and the fine control of uterine activity before and during parturition, reducing both the frequency and amplitude of uterine contractions. The levels of this hormone increase just before calving and act on a number of targets including the pelvic ligaments, cervix, myometrium and the mammary gland. Prostaglandins modify the effects of other hormones and are also important in the initiation of labour and control contractions of the smooth muscle of the uterus (Noakes *et al.*, 2001).

Maternal body temperature drops before calving and this change appears to show potential for the prediction of calving (Aoki *et al.*, 2005; Aoki *et al.*, 2006). The body temperature of the dam falls by 0.5-1°C in the last 24 hours before calving, and this can be used as an indicator of approaching parturition (Hulsen, 2006). It has also been suggested that cows are unlikely to calve during the next 12 hours if their body temperature is 39°C or higher (Noakes *et al.*, 2001). One study that looked at this in detail used data-logging apparatus to record the vaginal temperatures of 31 cows for six days before parturition. No significant differences were observed between 3-6 days before parturition but decreases were observed after this time. Two methods were used to compare the changes with normal daily variation. The best method used to predict calving from vaginal temperature was to compare the temperature with the corresponding time the previous day and if the decrease was more than 0.5°C for longer than three hours, calving can be expected within 60 hours. The onset of the drop in vaginal temperature before calving was the same for single and twin births and the vaginal temperature of the dam was not affected by maternal weight, parity, calf sex or calf weight (Aoki *et al.*, 2005). This consistent measurable change in body temperature before calving makes it a potentially useful option for the automated prediction of calving and at least two devices have been developed in this area. The Bovine Calving Monitor (made by Fujiya-Yano co. Ltd. Japan) includes a probe with a temperature sensor, that is inserted into the vagina, a transmitter and a receiver. The alarm is activated when the temperature falls below 35°C and this is reported to have worked successfully in all trials (Kubota *et al.*, 2000). The other device that is available is the Radco calving and foaling detector. This sounds an alarm when the difference in vaginal temperature, compared to the previous day, is larger than 0.4°C. The device continues to monitor the temperature after this point so that any increases can be detected that could indicate problems with parturition (Radco Alarm, 2009).

The expulsive forces that work to expel the foetus through the birth canal are one of the essential components of the birth process (Noakes *et al.*, 2001). The muscles of the uterus are very important during delivery and the essential physiological change between gestation and birth is the liberation of the contractile potential of the myometrium. For this to happen, the mechanisms that maintain pregnancy must be reversed. The most important of these is the removal of the progesterone block, which keeps the myometrium quiescent during gestation (Noakes *et al.*, 2001).

In addition to physical changes in the myometrium, there are also electrophysiological changes in the smooth muscle. During gestation there is an increase in the resting membrane potential. After the removal of the progesterone block and increase in oestrogen levels, there is a discharge of action potentials and myometrial contractions are initiated. Oestrogens increase the effectiveness of the myometrium as a contractile unit. The myometrial contractions show a transition from isolated, uncoordinated waves to more regular, coordinated peristaltic contractions nearer to expulsion. The frequency of contractions also increases from 12-24 per hour during the final two hours to 48 per hour just before expulsion. The myometrium alone acts during the first stage of parturition and contributes about 90% of the total expulsive effort, with the abdominal contractions assisting the delivery at critical stages (Noakes *et al.*, 2001). By monitoring the activity of the myometrium, the Agrimonitor cattle monitoring device is able to warn farmers when cows are about to calve (Agrimonitor, 2009). Difficult calvings can be distinguished by abnormal development of contractions in terms of intensity, duration and frequency. Two to six hours of baseline recordings are needed for this to work effectively and account for individual differences, but after this the Agrimonitor is claimed to be very effective at detecting calving and problems such as oversized calves and abnormal presentations.

1.5 Prevalence and effects of dystocia

Dystocia (calving difficulty) is an increasingly common problem in dairy cows. In most countries the reported prevalence of dystocia is between 2-7%, but is as high as 13% in the U.S. However, due to the lack of a standard scoring system and variation in the causes, it is difficult to determine these rates exactly (Mee, 2008).

As there is no uniform international system for the scoring of calving difficulty there are a number of different scales in use. Some countries have a national cattle database that will often include information on calving difficulty. Individual studies may use the national scoring system of the country or develop their own, depending on the specific research question being addressed and the local definition of what constitutes a normal or difficult calving. All scoring systems are generally described as ordered categories of increasing calving difficulty, with the highest scores generally given to cows requiring veterinary assistance (Meijering, 1984). However, the number of categories used varies from two (Bar-Anan *et al.*, 1987; Fourichon *et al.*, 2001; Wehrend *et al.*, 2006) to seven (Mee, 2008).

The simplest scales have two categories. These distinguish between difficult and normal calvings using a local definition of dystocia and all other calvings are regarded as normal. Bar-Anan *et al.* (1987) collected data from a number of herds in Israel with no definition of a difficult calving. Scores would be decided entirely subjectively by each person involved in the study. A better definition is used in the Finnish National Health Recording System where dystocia is diagnosed by a veterinarian and are all cases that required veterinary assistance (Rajala and Grohn, 1998). Another more objective system was used by Fourichon *et al.* (2001) who provided a definition of dystocia for on-farm data recording. This definition was "Assistance at calving with hard pull (calf puller or two persons pulling) or surgical calving (caesarean section or foetotomy)". This makes a clear distinction between which calvings are classed as dystocic or normal but still includes some degree of subjectivity.

There are some difficulties involved when trying to define a clear distinction between normal calvings and cows with dystocia because calving difficulty varies on a continuous scale. So, even if a good definition is provided for dystocia, this could still exclude some cows that experienced some difficulties with calving and may have been included in different circumstances. There is still some element of subjectivity involved with the decision to call for veterinary assistance or use a calving aid.

A possible improvement on a basic two point system is to include an extra category for cows that experienced some difficulties but not to an extent that would need veterinary assistance. This is the system used for the Norwegian Dairy Herd Recording System, where calving difficulty is classed as: 1. Easy calving, 2. Slight problems, 3. Calving difficulty (Heringstad *et al.*, 2007). There is still some level of subjectivity but the intermediate class allows a more definite distinction to be made between scores of 1 and 3.

Another way to improve on the basic two-point scale is to split the definition of dystocia into more than one group. This was done in a German study, in which calvings were classified as normal or one of three levels of veterinary assistance. These were: 1. Mild dystocia, including cows that needed only limited support, e.g. simple correction of malposition or limited traction, 2. Severe dystocia, heavy traction or extensive corrections of malpositions, 3. Caesarean section (if veterinarian in charge decided delivery of calf through birth canal was not possible without doing serious damage to dam or calf, or if calf was dead). This gave a total of four categories of calving difficulty (Tenhagen *et al.*, 2007).

However, other four-point scales also include classifications of less serious difficulties that do not require veterinary assistance. The Danish national cattle database includes calving difficulty scores consisting of four ordered categories: 1. Easy with no help, 2. Easy with assistance, 3. Difficult but without veterinary assistance, and 4. Difficult with veterinary assistance (Hansen *et al.*, 2004a). A study done in Ireland used categories for: 1. Unobserved calving, 2. Observed and unassisted at calving, 3. Cows that received some assistance, and 4. Cows that had a high degree of difficulty, culminating in the use of a calving aid or veterinary assistance (Buckley *et al.*, 2003).

Five point scales of calving difficulty are most frequently used in North America and Canada. These all agree on the first category, which is a normal, unassisted calving, but differ slightly thereafter. The scale used by the national Association of Animal Breeders in the United States can be used as a standard to compare the other scales with. This scale specifies calving difficulty scores of: 1. No problem, 2. Slight problem, 3. Needed assistance, 4. Considerable force, and 5. Extreme difficulty (Adamec *et al.*, 2006).

A Californian study included calf viability in the definition of the unassisted deliveries, giving scores on a 1-4 scale: 1. No assistance with normal delivery of a live calf, 2. No assistance with delivery of a stillborn calf, 3. Some assistance required for extraction of a calf, 4. Difficult calving with forced extraction of the calf. Cows requiring a foetotomy or caesarean section were excluded from the study (Ettema and Santos, 2004).

In the Holstein-Friesian Association of Canada database, calving ease is recorded by the farmer as a routine part of the data collection programme of DHAS and was assigned to one of five categories: 1. Unobserved or unassisted, 2. Easy pull, 3. Hard pull, 4. Surgical intervention, and 5. Malpresentations. The malpresentations were excluded from the analysis because it was not recorded whether these were unassisted, easy pull, hard pull or required surgical intervention (Cue *et al.*, 1990).

Another variation was to include the duration of labour to differentiate between levels of difficulty in U.S. dairy Holstein crosses. This was also a five-point scale, with 1. Quick, easy birth with no assistance, 2. Over two hours in labour, but no assistance, 3. Minimum assistance, but no calving difficulty, 4. Obstetrical chains used, and 5. Extremely difficult birth requiring a mechanical puller (Heins *et al.*, 2006).

Dystocia can also be scored based on the amount of assistance that was provided. An example, again with five categories is; 1. No assistance required, 2. Required intervention by one person with the use of a mechanical aid (mild dystocia), 3. Required the assistance of two or more people, 4. Mechanical extraction, 5. Surgical procedures (Lombard *et al.*, 2007).

The maximum number of categories used was found on the Australian Dairy Herd Improvement Scheme (ADHIS) website (Australian Dairy Herd Improvement Scheme, 2009). Seven levels were listed as: 1. Unobserved, not OK, 2. Unobserved, OK, 3. Observed, OK, 4. Observed, easy pull, 5. Observed, very difficult, 6. Observed, surgical, 7. Observed, malpresentation.

The scoring systems that have been described are all from the literature on dairy cows but very similar methods are used for beef cattle. The only method of scoring calving difficulty that is different and as objective as possible, is measuring the applied traction pressure needed to deliver calves requiring assistance. This was done using a gauge attached to a calf puller and recorded as the kilogram-force (non-SI unit for pressure). Scores on the fairly standard five-point scale were each assigned a range of traction pressure: 1. No assistance, 2. Easy pull; 33-56 kg, 3. Mechanical pull; 57-281 kg, 4. Hard mechanical pull; 282-364 kg, 5. Caesarean section (Colburn *et al.*, 1997).

There are a range of causes of dystocia, which can result from problems relating to any of the essential components of the birth process. These are the expulsive forces, the foetus and the birth canal; normal birth results when the forces are sufficient to expel a normal, correctly presented foetus through an adequately-sized birth canal (Noakes *et al.*, 2001). A wide variety of related causes can result in problems with these components of a normal calving (Figure 1.04).

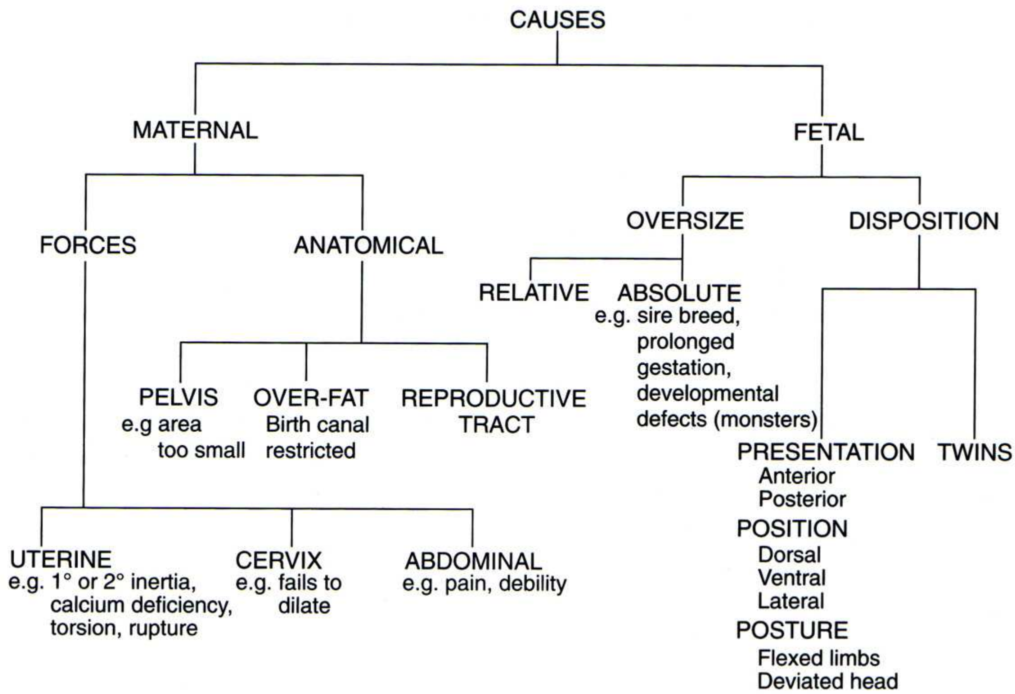

Figure 1.04
A summary of potential causes of dystocia in cattle (from Ball and Peters, 2004). Both maternal and foetal characteristics can have an influence on calving difficulty and combinations of more than one cause are possible.

Some causes of calving difficulties are inter-related and various factors can contribute to the immediate cause of problems. One example of this would be foeto-pelvic disproportion as the immediate cause of calving difficulty, which can result from a number of intermediate factors such as foetal oversize, birth canal undersize and gestation length. Then another level of ultimate factors contribute to these, in turn. For example, the influence of foetal characteristics including gender, abnormalities, multiple foetuses and sire breed on foetal oversize (Mee, 2008).

The extension of the forelimbs by the foetus is essential for the correct presentation and posture to be achieved for a normal, uncomplicated birth (Figure 1.05).

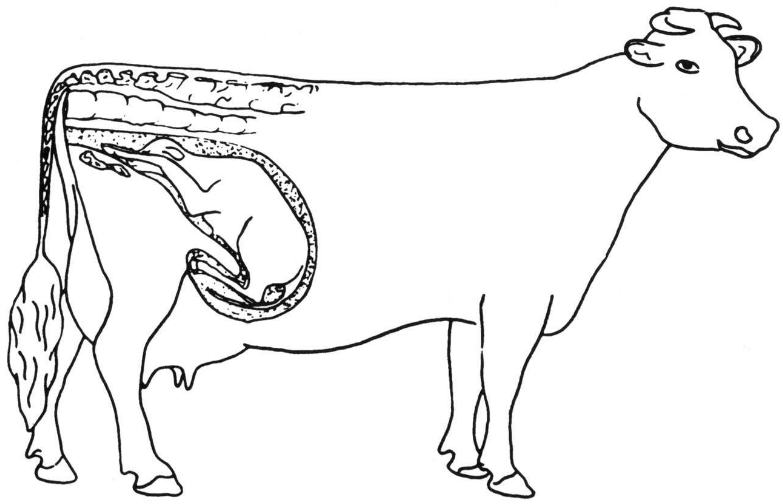

Figure 1.05
Correct anterior presentation and position of the calf immediately prior to birth (from Ball and Peters, 2004)

The spontaneous foetal movements required for the extension of the forelimbs occur in response to an increase in uterine pressure caused by uterine contractions during the first stage of parturition. Therefore, uterine inertia in the dam may be a contributory cause of malpresentation of the foetus (Noakes *et al.*, 2001). Malpresentation is one of the main problems requiring human intervention at calving. The presentation and posture of the foetus can be abnormal in a number of ways (Figure 1.06).

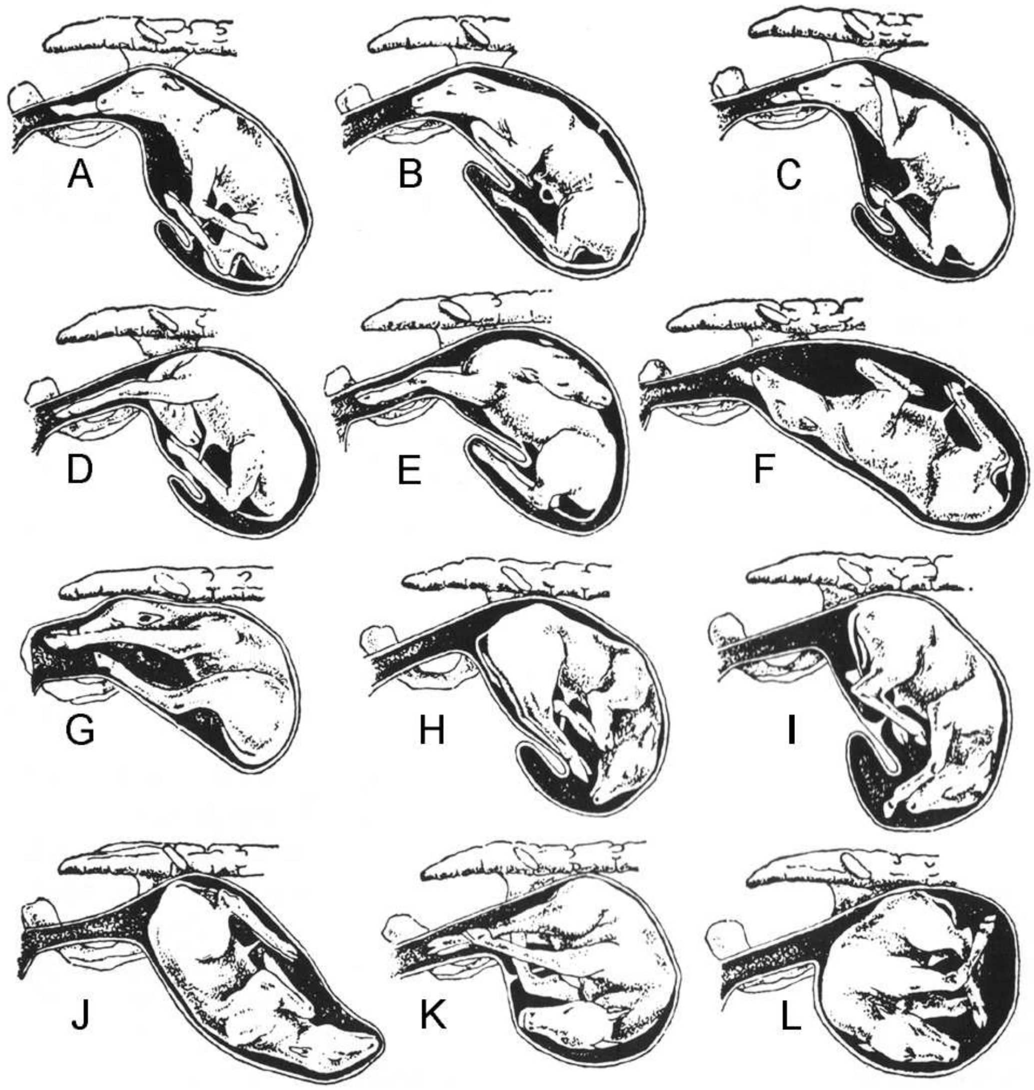

Figure 1.06
Abnormal presentations for delivery. A, anterior presentation, one foreleg back. B, anterior presentation, forelegs bent at knee. C, anterior presentation, forelegs crossed over neck. D, anterior presentation, downward deviation of head. E, anterior presentation, upward deviation of head. F, anterior presentation with back down. G, anterior presentation, with hind feet in pelvis. H, croup and thigh presentation. I, croup and hock presentation. J, posterior presentation, foetus on its back. K, all feet presented. L, dorsolumbar presentation (from Frandson and Spurgeon, 1992).

These abnormal presentations occur at different frequencies, with some more commonly seen than others. In studies of malpresentation in beef cattle, with 4% (Holland *et al.*, 1993) and 1% (Nix *et al.*, 1998) of calves abnormally presented, around 70% of these abnormalities were posterior presentations. Leg deviations were the next most frequent problem, observed in around 10-15% of malpresented calves, and other abnormal presentations were observed at lower frequencies than this (Holland *et al.*, 1993; Nix *et al.*, 1998).

Dystocia is a major factor contributing to neonatal and postnatal mortality within the first ten days of life and accounted for around half the deaths in a post-mortem study of beef cattle. The overall mortality rate in this study was 6.7% of calves from 13,296 calvings over 15 years. Calves that were classed as dying from delayed and difficult parturition showed bruising, contusions, haemorrhages, bone fractures and joint dislocations. Those born backwards, or in breech presentations, had a swollen tongue and head, with bruises and haemorrhages on the rump and rear legs. However, a large proportion of these deaths may have been avoidable if the problems had been identified and corrected in time. In addition, appropriate and timely assistance could have prevented the damage and injuries caused by the prolonged duration of parturition (Bellows *et al.*, 1987).

Severe cases of dystocia can increase the incidence of cow and calf mortality but even in less serious cases it can cause considerable pain and distress. In a survey of cattle practitioners in Ireland, dystocia (foeto-pelvic disproportion requiring traction alone) was ranked as one of the most painful conditions experienced by cattle (Huxley and Whay, 2006). Prolonged labour also affects the dam and has a detrimental effect on subsequent reproductive performance that can be avoided if early, correct obstetrical assistance is given (Bellows *et al.*, 1988). When both short-term and long-term effects such as reduced milk yields are considered, calving problems are very expensive for farmers. One study showed that a slightly difficult calving in the UK costs £110 and a seriously difficult calving can cost £350 - £400, depending on the veterinary costs (McGuirk *et al.*, 2007).

However, care must also be taken to not interfere prematurely with calving as this can increase the risk of infections, damage to the birth canal or bursting of the water bag. If given time, 90% of cows will calve naturally within two hours, and 50% of heifers will calve within three hours of the start of calving (Ramsbottom and Stokes, 2009). For these reasons, cows should be kept under frequent observation from the time when they show complete relaxation of the pelvic ligaments and be examined if there is no straining after 12 hours of restlessness to identify any cases of uterine inertia, incomplete cervical dilation or uterine torsion (Noakes *et al.*, 2001).

When intervention is required, it is important that this is done carefully by trained staff because interference can damage both the dam and the calf. Calves can be lost due to technician error and usually have varying numbers of broken ribs. In a post-mortem study of 798 beef calves the cause of death of nine calves was determined to be due to technician error. For three of these calves the error was incorrect positioning of the calving jack so that the sternum of the calf struck the jack as it exited the vulva. The other six calves had broken ribs from herdsmen applying artificial respiration (administered by alternately exerting and releasing pressure on the rib cage) using excessive pressure. Excessive traction with a foetal extractor or improper placement of obstetrical chains and straps can also cause fractured or broken metacarpal, metatarsal and phalanx bones (Bellows *et al.*, 1987).

It is consistently observed that heifers are more likely to experience difficulties at calving (Bleul, 2008; Lombard *et al.*, 2007; Nix *et al.*, 1998). This might be partially due to the early age of first calving in many heifers. Heifers are often calved when they are around two years old to increase profits. However, heifers calved when two years old have a 7.0% incidence of assisted calvings compared to only 1.7% of those calved at three years of age (Ettema and Santos, 2004).

It may be possible to prevent some cases of dystocia, although other causes will always occur spontaneously and cannot be avoided. Careful sire selection can help minimise the risk of foetal oversize, especially in heifers (Mee, 2008). Some cases of dystocia can also be prevented or minimised with careful management, such as good husbandry and healthcare during the transition period. The provision of a stress-free calving environment is important as parturient stress can intensify any problems (Mee, 2008). Excess body fat can also cause problems at calving by decreasing the size of the pelvic canal, but this is only likely to be a problem in very fat cows. However, problems due to malpresentation of the foetus are more difficult to prevent (Noakes *et al.*, 2001). Where possible, prevention would be preferable to high rates of assistance as this can be problematic.

1.6 Accelerometers and their application for measuring behaviour

An accelerometer is an electromechanical device that measures acceleration forces; more accurately described as the time-rate of change of velocity. They measure both static forces, such as gravity, and dynamic forces from movement or vibration. There are various types available but piezoelectric accelerometers are the most commonly used for measuring animal behaviour. The use of accelerometers for recording behaviour is an active area of research. The main literature on this topic is summarised in Table 1.02.

This approach has been applied to a wide range of terrestrial and aquatic species but similar analysis methods have been used. These range from simple identification of characteristic patterns (Yoda *et al.*, 1999) to more complex analyses of cyclic behaviours (Kawabe *et al.*, 2003; Watanabe *et al.*, 2005; Scheibe and Gromann, 2006). Threshold values are used to distinguish between behaviours (Yamada and Tokuriki, 2000; Sellers and Crompton, 2004; Tsuda *et al.*, 2006) and also to provide activity scores (Berger *et al.*, 1999; Van Oort *et al.*, 2004; Mann *et al.*, 2005; Pepin *et al.*, 2006).

In humans, accelerometers have been used for; measuring activity levels in young children (Tulve *et al.*, 2007), clinical assessment of posture and movement, (Wong *et al.*, 2007) and long-term monitoring of elderly people (Allen *et al.*, 2006; Karantonis *et al.*, 2006). The monitoring of elderly individuals is the most comparable application to the current project. A waist-mounted tri-axial accelerometer was used to identify when people stood, walked or lay down (Allen *et al.*, 2006) and also identified walking and falls (Karantonis *et al.*, 2006).

Table 1.02 Summary of existing publications on the use of accelerometers for measuring behaviour

Species	Axes	Hz	Range (g)	Name of sensor	Methods of analysis	Behaviours identified	Reference
Cow Horse	3	100	±4	Ethosys®	Frequency distributions with standard deviations, spectral analyses, fractal analyses	Standing, grazing, walking, ruminating, drinking, hay uptake	Scheibe & Gromann, 2006
Cow	-	8	-	Ice Tag®	-	Standing, walking, lying	Blackie et al., 2006
Beagle dog	3	10	0.01-4	Activtracer ®	Range of threshold values set for groups of behaviours	Locomotion, postural change, + movement of body within postures	Yamada & Tokuriki, 2000
Marmoset	3	-	>0.5	Actiwatch® Mini	(activity score calculated by Actiwatch® every hour)	Activity scores	Mann *et al.*, 2005
Adelie penguins	2	1	±1.2	-	Patterns identified – increased during jump phase, lower and constant during subsurface swimming	Porpoising behaviour	Yoda *et al.*, 1999
Chum salmon	2	8-32	±5	-	Low-pass filter. Data smoothed using moving average. Maximum amplitudes.	Swimming, nosing, exploratory/nest/post-spawning digging, probing, oviposition, covering	Tsuda *et al.*, 2006
Japanese flounder	2	16	±4	-	Filtered (0.5-8.0Hz) Auto-correlation and Fast Fourier Transform (for dynamic, periodic behaviour)	Active swimming, burying patterns, inactive gliding, lying on the bottom	Kawabe *et al.*, 2003
Red-ruffed lemur	1	100	±5	-	Data filtered to remove frequencies <0.2Hz and >5Hz. Divided into 256 sample blocks Peak acceleration measured, above 1.7g = leap occurred. Values below examined for cyclic locomotion – from root means squared amplitude of waveform	Leaping Cyclic activities less well characterised	Sellers & Crompton, 2004
Domestic cat	1	16	±3	-	Spectral analysis, Fast Fourier Transform	Body postures. Drinking, eating, several paces of travelling	Watanabe *et al.*, 2005
Przewalski horse	1	>8	-	Ethosys®	Activity (+/-) scored every second. Frequency filters used to identify feeding	Activity (+ head position sensor > feeding)	Berger *et al.*, 1999
Red deer	1	>8	-	Ethosys®	Activity (+/-) scored every second. Frequency filters used to identify eating + ruminating	Activity (+ head position sensor > eating + ruminating)	Pepin *et al.*, 2006
Reindeer	1	32	-	Actiwatch®	Analysis of frequency distribution – bimodal – active/inactive. Thresholds identified	Active/inactive	Van Oort *et al.*, 2004

Accelerometers have also been used previously to research the behaviour of dairy cows. Blackie *et al.* (2006) attached Ice Tags ™ containing accelerometers to the back right leg, above the fetlock of 25 early lactation Holstein cows. These devices calculated the hours per day spent standing, lying or active.

Another study attached an Actiwatch® to the hind leg of 12 dairy cows to measure high or low activity levels. The measurements were validated using video recordings and it was shown that this method could distinguish the number of lying bouts, although no specific behaviours were recorded. However, lying could be identified from very low activity (Müller and Schrader, 2003).

Accelerometer devices attached to collars around the neck have also been used in dairy cattle. The Ethosys® system is able to identify basic behaviours such as standing, grazing, walking, ruminating, drinking and hay uptake (Scheibe and Gromann, 2006). This shows that many behaviours can be measured from the neck position and that leg sensors are not essential to measure activity.

1.7 Aims of thesis

The central aim of this thesis is to investigate the use of behavioural, accelerometer and heart rate measurements to predict calving in dairy cows.

The main aims of each chapter are summarised below. These are divided into multiple research aims at the beginning of each respective chapter.

- Chapter 3. *Part 1.* To identify any variables from the calving records that could be used to predict calving. *Part 2.* To identify any risk factors from the calving records associated with various problems during the transition period.

- Chapter 4. To identify changes in behaviour that occur during the 24 hours before normal calving and may be useful for predicting parturition.

- Chapter 5. To identify any differences in behaviour before calving between cows and heifers, and between those that are given assistance at calving and those that are not.

- Chapter 6. To investigate if features in three-axis accelerometer data, that correspond to specific behaviours, can be identified by examining the relationship between accelerometer data and behavioural observations.

- Chapter 7. To establish if there is a change in the heart rate or heart rate variability of dairy cows during the last six to ten weeks of pregnancy.

Chapter 2: Materials and Methods

2.1 Management and herd information

All data were collected at Langhill Dairy Farm, Roslin, Midlothian, U.K. which has a milking herd of around 220 Holstein-Friesian cows. As a commercial dairy farm, the husbandry and management of the animals at Langhill are comparable to that of most dairy farms in the U.K. The management of the cows during drying off and the transition period is summarised in Figure 2.01.

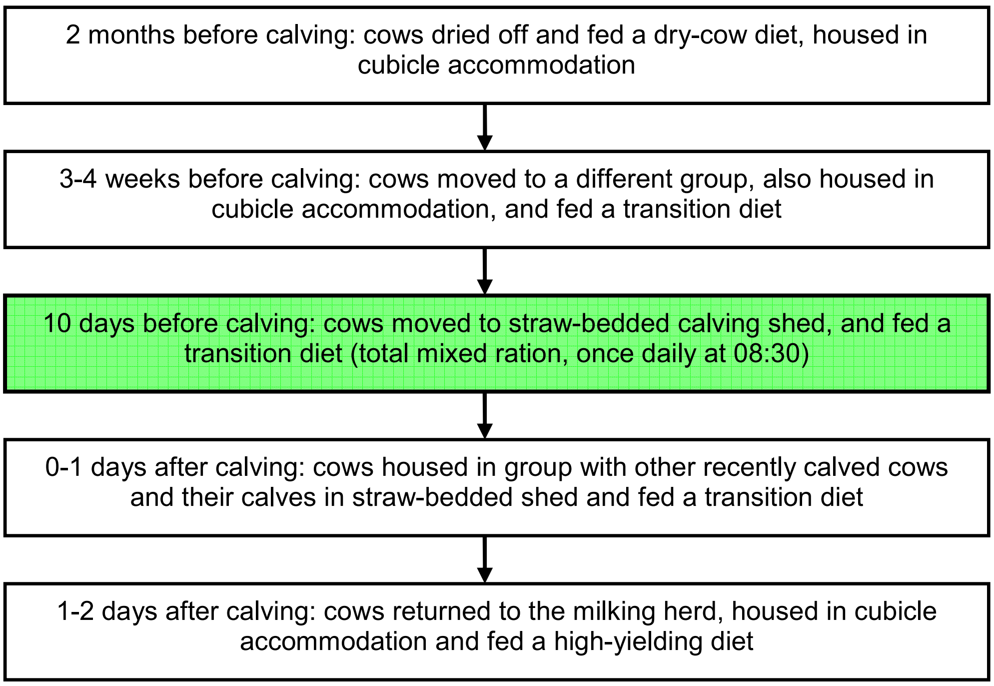

Figure 2.01
Transition cow movements and feeding during the transition period at Langhill farm. The stage during which the cows were studied is highlighted in green.

Group-housing could potentially inhibit calving if cows are unable to find a suitable calving site where they will not be disturbed by other cows in the group.

The calving season starts in late August and ends in early May. Ideally few cows would calve later than March so they can conceive in time for the next calving season and therefore minimise the number of cows which miss a calving season ("carryovers") or are culled. The calving patterns during the two calving seasons in this study are shown in Figure 2.02.

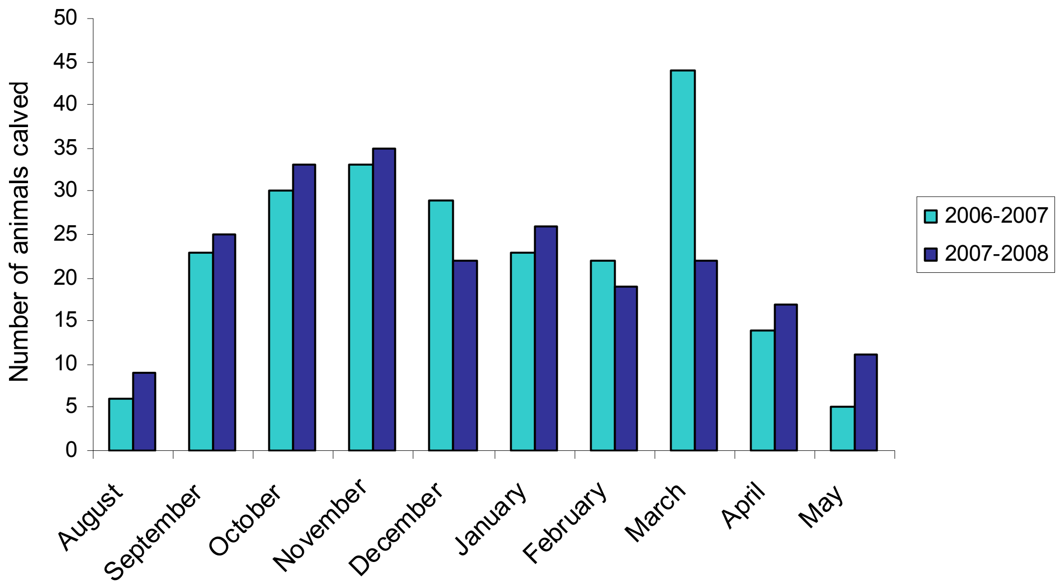

Figure 2.02
The calving pattern of cows and heifers at Langhill Farm, shown as the number of calvings each month during the two years of the study.

The calving pattern seen in 2007-2008 was closer to the desired pattern, with a peak in calvings before December. However, in 2006-2007, fertility problems led to reduced numbers of cows calving earlier in the season and a large peak of calvings during March as a result of increased effort to get cows pregnant towards the end of the previous spring.

The herd includes a large number of heifers and relatively few cows on their sixth or later lactation. The age composition is shown in Figure 2.03.

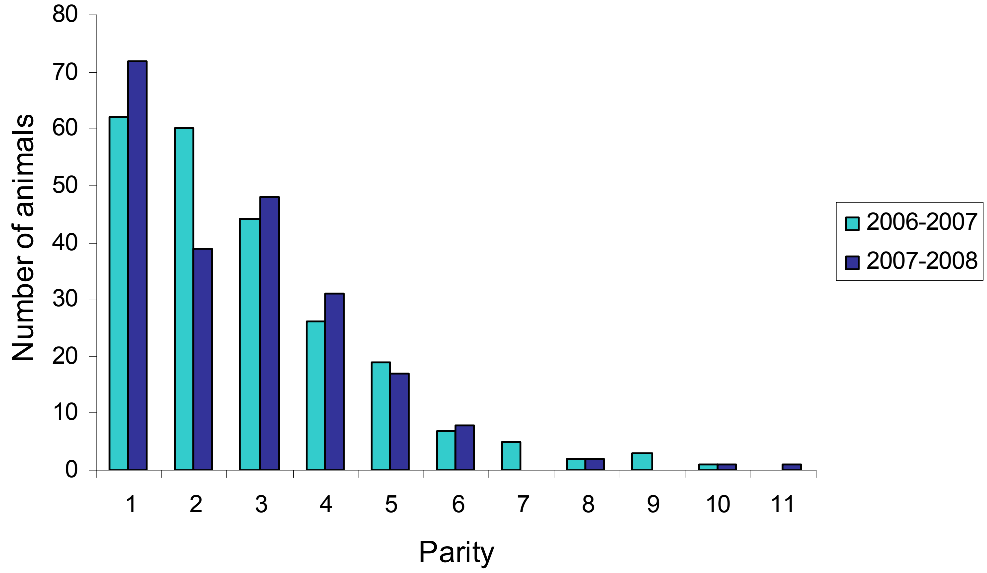

Figure 2.03
The parities of animals that calved in 2006-2007 and 2007-2008. Many individuals were in the herd for both years.

The average time a dairy cow is in the herd before she is culled is three lactations in the UK (Compassion in World Farming, 2009). If cows are kept less intensively they can live for 20-25 years (Phillips, 2001).

Heifers were around two years old at the time of their first calving. At the beginning of the breeding season most cows and heifers were artificially inseminated with dairy semen, and sexed semen was used for heifers to bias the sex ratio towards female calves. This is common practice to increase the number of replacement heifers produced to join the dairy herd (Hohenboken, 1999). After this point, male calves are more valuable because of their more efficient growth rate for meat production (Berry and Cromie, 2007). Once enough replacement heifers have been born, beef-cross calves are more profitable, so beef semen is used towards the end of the breeding season. Cows and heifers that take longer to conceive and therefore fall towards the end of the calving season are either artificially inseminated with Fertility Plus or allowed access to a Hereford sweeper bull for natural mating. This leads to an uneven distribution of calvings from dairy and beef sires across the season (Figure 2.04).

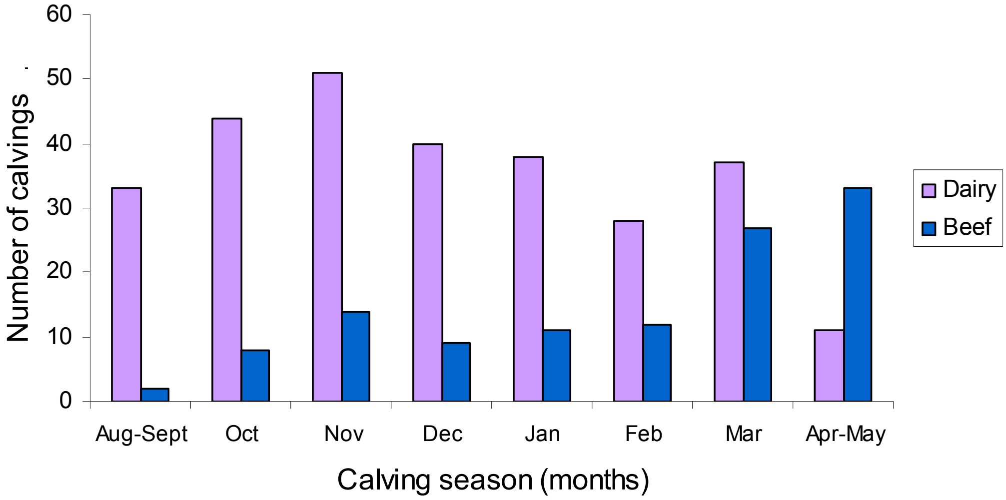

Figure 2.04
The number of calvings from dairy and beef sires over the course of the calving seasons (both years combined). Most animals calved to dairy sires up until March, but in April and May more calved to beef sires.

In 2006-2007, 19 pairs of twins and 210 singleton calves were born (8.3% twins) and in 2007-2008 there were 13 twin births and 206 single calves born (5.9% twins). These are both higher than the average percentage of 4.8% reported by Kossaibati and Esslemont (1997). Heifers had fewer twin calvings (1.5%) than cows (9.0%). This increase in twin calvings with age was reviewed by Wiltbank *et al.* (2000) who found that, in all of the studies done, the largest increase in twinning was observed between the first and second calvings. The twinning rate for heifers was around 1%, increasing to 6-7% for cows having their second calf, and then continued to increase slightly in later lactations.

Calf weights were only available for live calves and were recorded when they were two to three days old. Data were only collected in 2006-2007 for 145 calves. Twin calves weighed less than single calves, with average (mean ± standard deviation) weights of 42.07 ± 6.15 kg (n = 15) compared with 47.01 ± 4.96 kg (n = 130). Male calves weighed an average of 49.53 ± 5.19 kg (n = 49) and were heavier than female calves that weighed 45.44 ± 4.06 kg (n = 68), on average. Dairy calves were lighter at 46.05 ± 4.64 kg (n = 73) than beef calves which weighed an average of 50.15 ± 6.62 kg (n = 20) and calves from heifers weighed slightly more than those from cows. Single calf weights were positively correlated with gestation length, with longer gestations producing heavier calves (Figure 2.05).

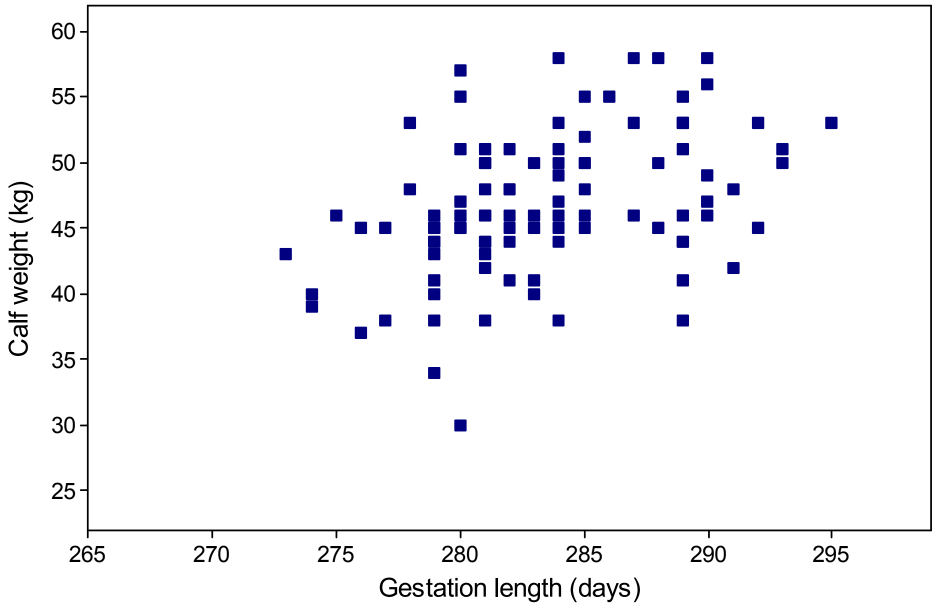

Figure 2.05
Scatter plot showing the significant positive correlation found between gestation length and calf weight ($F_{1,91}$ = 20.38, p < 0.001).

2.2 Farm records

The stockmen were asked to complete sheets recording a number of details about each calving. The format of this information sheet is shown in Table 2.01.

Table 2.01 Headings used by stockmen to record details of each calving, including definitions for levels of assistance.

Individual freeze brand number				
Date of calving				
Time first noticed starting to calve				
Reason for noticing starting to calve				
Time calf born				
Calf live/dead				
Calf sex				
Degree of assistance*				
Reason for assistance				
Calved by				
Notes				
Problems				

*Degree of assistance:
NORMAL - unassisted delivery (or unobserved)
MINOR - uncomplicated assistance - gentle pull
JACK - assistance with two persons or calving jack
VET - veterinary assistance required
CAESAREAN

These records and insemination details from the farm database were collated into the following variables for the analyses in Chapter 3.

Year and month. The year (Year 1: 2006-2007 and Year 2: 2007-2008) and month of calving were taken from the record sheet for each cow.

Gestation length. Gestation lengths were calculated as the time from the successful insemination dates, confirmed by veterinary pregnancy diagnosis, in the farm database until the date of calving. Any that were more than 14 days either side of the expected average gestation length of 282 days for Holstein-Friesian cows (Fisher and Williams, 1978) were believed to have held to an earlier or later service and were excluded from the dataset. This ensured that the data were not skewed by inaccurate estimates of gestation length. Meyer *et al.* (2001) also excluded records with gestation lengths that were more than two standard deviations (15 days) from the mean. The mean gestation lengths in this study were 283.3 ± 5.0 (S.D.) days and 281.6 ± 4.7 (S.D.) days in the 2006-2007 and 2007-2008 calving seasons, respectively.

Time of day. The exact times were not available for when each calf was born, as there was not always someone present, so times were also simplified into day (06:00-18:00) and night time (18:00-06:00). This arbitrary division between day and night was used because it was considered the most appropriate and was used in other studies (Pennington and Albright, 1985; Tharmaraj *et al.*, 1989).

Calving interval. These were calculated as the time between calvings for cows that were in the records for both consecutive years.

Parity. The lactation number of each dam was known from the insemination records. Parities were recorded as both the lactation number and as a two-factor variable; cow or heifer. The ages at first calving were also obtained for heifers.

Stockman. The stockman present at each calving was given as their initials. If two sets of initials were noted this was listed as two men, and any case where a veterinarian was present was recorded as veterinary assisted.

Sire. The sire information was available from the insemination records and was categorised as beef or dairy.

Twin. Twin calvings were recorded in the stockmen's notes. The inclusion of twin calves in the analyses is specified in each case with the results.

Calf survival. Calves were scored as live, dead, or died within the first two days after birth. Those that died within the first two days were grouped with the dead calves for many of the analyses.

Assistance. The stockmen used the following five levels of assistance to classify each calving that they attended; normal, minor, jack, veterinary, caesarean. The decision to assist was made by the stockmen based on their own opinions and experience.

Milk fever. Cases of milk fever were recorded on the calving sheet if cows were given calcium within the first few days following parturition.

Calf weight. Calves were weighed before being moved to the calving shed at two to three days old. Dead calves were not weighed.

Calf sex. The sex of each calf was also entered on the calving sheets.

The stockmen were asked to write down what they observed to be the first signs of calving, rather than choosing them from a fixed list of terms. The signs of calving recorded by the farm staff were simplified into categories of synonymous terms, and the time from when the first signs were noticed until the calf was born was classified as <1 h, 1-2 h, 2-3 h, 3-4 h, 4-6 h and >6 hours. When calves were born unnoticed, this was recorded as "calf found" and assigned a time of 0 hours.

Calving records from 448 calvings (229 during 2006-2007, and 219 during 2007-2008) were examined. This included all of the cows that calved during this two-year period. The number of individual cows included in this dataset was 323, with 125 cows calving both years. Records from cows with aborted calves were not included in the dataset. Those with gestation lengths shorter than 240 days were classed as abortions (Hansen *et al.*, 2004b).

2.3 Video recordings

Cows were group-housed in a large straw-bedded shed, so this is where observations were made and the video cameras installed. Sixteen monochrome video cameras (Panasonic WV-BP120) with 1/3" fixed iris lenses (Panasonic WV-LF4R5C3AE) were installed in the transition dry-cow shed in a way that gave the best possible view of activity across the whole shed. Only the crush where cows had their collars checked and changed was not covered by the cameras (Figure 2.06).

Figure 2.06
Image taken from video recordings of calving shed, showing the views from each of the 16 cameras. These were the final positions used for the majority of the study.

The signal from the cameras went through a video multiplexer (Panasonic WJ-FS616) to record 24 hours onto a single 4-h video tape using a time-lapse video cassette recorder (Sanyo SRT-8960P). This time setting gave a resolution of one frame per second, for each camera view.

For subsequent computer analysis, a vertical interval time code (VITC) generator was connected between the multiplexer and video recorder to insert a VITC signal onto each videotape during recording. The equipment and wiring is illustrated in Figure 2.07.

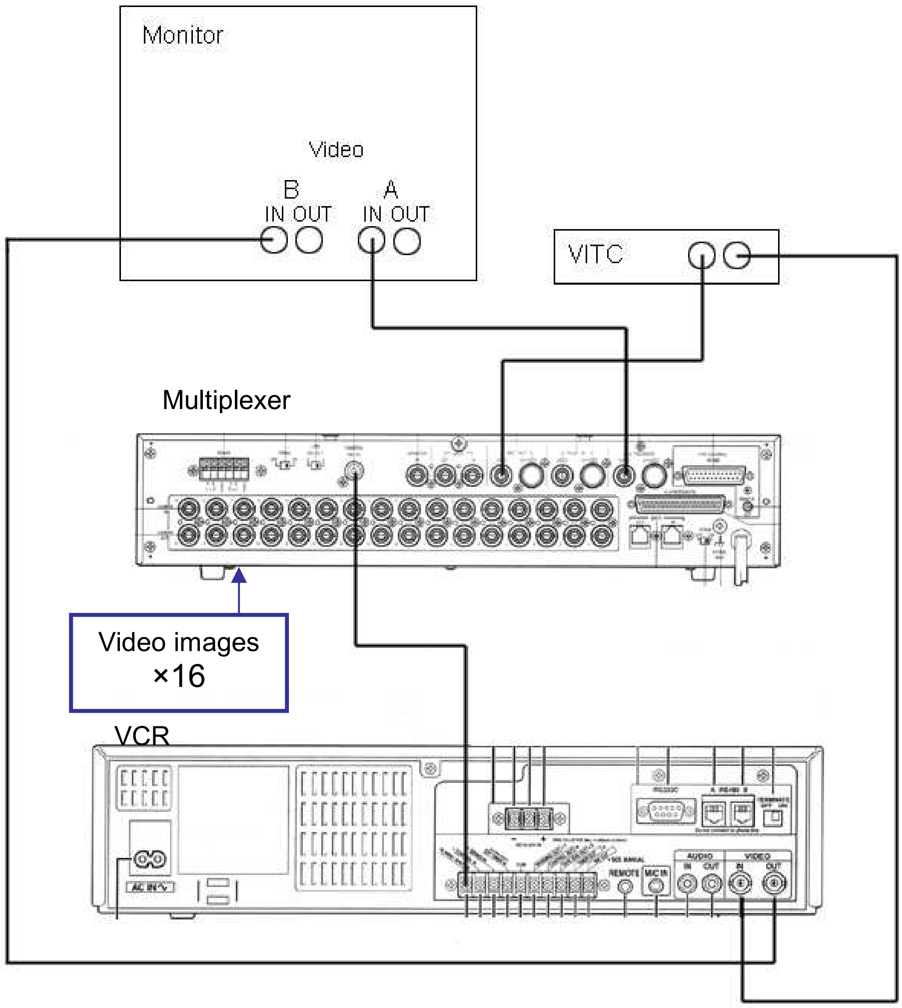

Figure 2.07
This diagram shows the equipment that was used to record videos of the events in the calving shed, and how it was wired. The individual cables from each camera are not shown but these were connected to the 16 ports in the back of the multiplexer.

The time on the video recorder, which was visible on the recordings, was set using a radio controlled clock (Acctim Stratus 74057). This clock received an accurate time signal via radio waves at least once daily, with less than a second of drift per day. The synchronisation of the video time with this clock was checked every 3-4 weeks to minimise the effect of drift on the alignment of videos with accelerometer recordings. The drift was found to be minimal, so monthly checks were considered adequate. The video tapes were changed at around the same time each morning (between 08:30-09:00), leaving a gap of approximately 30 seconds between videos.

The area under observation was naturally lit during daylight hours, with additional artificial lighting when stockmen were present, until approximately 22:00 at night until 05:00 in the morning. The lights were also switched on when stockmen came to check the cows between these times. Infra-red lighting was used for night-time recording. This was activated by an automatic sensor that recognised when the light intensity dropped below a threshold value and switched on the infra-red lights and the video to black-and-white recording when light levels were low. This provided continuous footage of the calving shed, with colour recordings during daylight and black-and-white recordings during the night.

The analysis of behaviour from video recordings avoided the chance of there being any observer effects on the behaviour of the focal animals. This also meant that there was minimal disturbance of the animals around this sensitive time. As the videos were watched retrospectively, there was no opportunity to intervene with events and no changes were made to the management of the animals (Martin and Bateson, 2007).

New videotapes were “packed” before recording. This involved fast-forwarding each tape to the end and rewinding again before they were used. This was done to wind the tape to the appropriate tension for the VCR and improve the quality of recording. Once recorded, videos were labelled with the date and stored upright with the wound spool at the bottom to avoid stretching or distortion of the tape.

There were only up to 20 cows in the calving shed at any time so it was possible to identify them from their individual markings and freeze-brand numbers. However, to make this easier many of the cows were also spray-marked with large numbers (2006-2007) or letters (2007-2008) using Arco Line Marker spray paint. These were mainly cows that were fitted with collars for accelerometer recordings. The cows were regularly restrained to allow their collars to be checked or changed so their markings were refreshed at least once a week. This made individual identification from the video recordings much more straightforward (Figure 2.08).

Figure 2.08
An image from the video recordings of cows with spray-painted numbers to aid identification.

2.4 Behavioural analysis

2.4.1 Computer equipment

For the analysis of the video recordings, a separate video system was set up and connected to a personal computer with a vertical interval time code (VITC) reader installed (Figure 2.09).

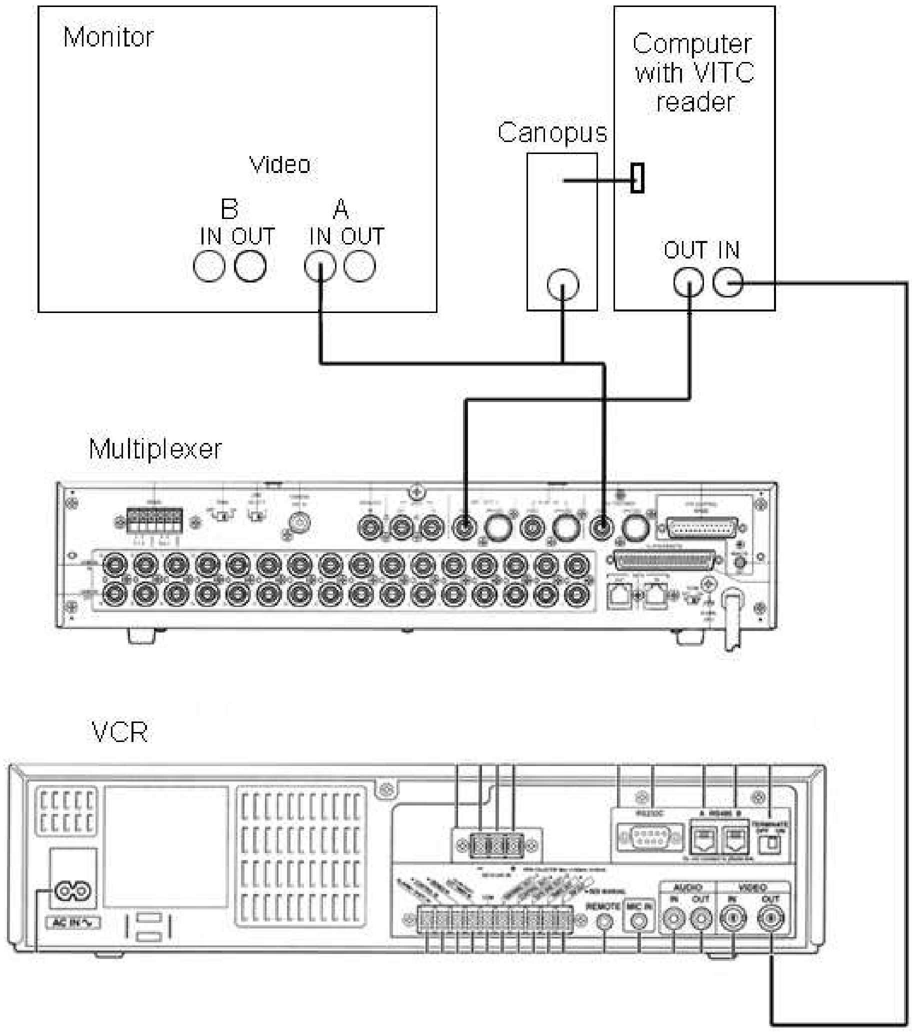

Figure 2.09
The equipment used for the analysis of video recordings made of the calving shed. A multiplexer was required to view the multiple images recorded onto each tape, and the VCR was also connected to a computer with a reader for the video time code. The Canopus USB-device allowed digital images or short clips to be saved from the videos.

The Observer® software version 5.0 (Noldus Information Technology bv., 2004) was used to collect behavioural data from the video recordings of the cows.

When using this software, an individual cow's behaviour is observed on the monitor and behaviour is entered on the computer in the form of codes. These codes are specified during configuration of the software. The output produced shows the coded behaviours with the time of each behaviour, which is obtained by the software from the VITC reader.

Behaviours were grouped into different mutually-exclusive states, and events that were defined in the ethogram for the study.

2.4.2 Ethogram

An ethogram was designed to serve two purposes. The first was to capture the changes in behaviour during the time before parturition, and the second was to see how the data collected from the accelerometers could be explained by the movements of the cow. In each chapter where behavioural data is used, the behaviours included in the analyses will be specified.

Some changes were made during the first season of recording, to improve the quality of data collected, and the final full version (Table 2.02) was produced. All of the modifications made to the ethogram remained compatible with previous versions, with any new behaviours arising from combinations of existing behaviours or behaviours that were split into additional states.

Table 2.02 Ethogram used to set up the Observer configuration for the analysis of calving behaviour from video recordings.

A - Posture

Standing	State A	Cow supported on all four legs, no forward or backward movement.
Walking	State A	Cow stepping, moving forwards or backwards.
Lying	State A	Cow lying down with body in contact with the ground.

B – Head position

Head up	State B	Standing - head held at height of back, or higher. Lying – head held off the ground.
Head down	State B	Standing – head held below height of back. Lying – head resting on the ground.
Head turn	Event	Head turned more than 90° from normal forward position, looking along flanks. Each turn is separated by the head returning to forward position.

C - Behaviour

Eating	State C	Cow places head through feed barrier and eats, with muzzle no more than 10cm away from the silage.
Drinking	State C	Cow moves muzzle within 10cm of water in trough. Ends when muzzle is more than 10cm away from water.
Licking ground	State C	Cow holds muzzle within 10cm of ground (may see tongue protrusion). Ends when cow moves muzzle more than 10cm away from ground.
Grooming	State C	Cow licking herself or another cow.
Ruminating	State C	Characteristic lateral movements of the jaws. Ends when cow has not ruminated for 10 seconds.
Other	State C	Cow not engaged in any of the above activities.

D - Intervention

No intervention	State D	No people present in the same pen as the focal animal.
Enter pen	State D	One or more people in the same pen as the focal animal, but not making any physical contact.
Intervention	State D	One of more people actively involved in an intervention with the focal animal.

Table 2.02 (continued)

E - View of cow

Whole cow	State E	Whole cow visible on the screen.
No rumination	State E	Cow visible but orientation or distance from camera means that rumination cannot be recorded reliably.
No tail	State E	Cow visible but tail hidden from view due to orientation of cow, or hidden behind another cow.
No rumination or tail	State E	Both the tail and rumination behaviour of the focal cow cannot be recorded reliably.
Out of sight	State E	Cow hidden from view by another cow, or out of the area covered by the video cameras.

Events

Tail raise	Event (Year 2 – State X)	Tail raised and held away from body. Each tail raise is separated by tail returning to relaxed position.
Tail down (Year 2 only)	State X	Tail returned to a relaxed position.
Tail swish	Event	Tail swung to the side and then forcefully forward along the flanks or directly back down.
Stamp	Event	Fore or hind leg raised, foot either reaches forward and down or returned directly to the ground with force.
Contraction	Event	Standing – back arched, head and neck extended, tail raised and extended, visible muscle contraction in abdomen. Lying – one or more legs extended, abdominal straining. Interval between contractions determined by relaxation of muscles and return of posture to normal.
Water bag burst	Event	Moment when the water bag bursts. Cow may show intense interest in licking the area where this happens.
Calf expelled	Event	Calf free from the cow's vulva. Standing - when the hips have passed through and the calf falls away from the cow. Lying - either when the cow stands, or when the calf moves away from the cow.

Lying behaviour was originally split into lateral and ventral lying, to show shifts in position. Although these two lying positions are easily distinguished, the intermediate position of semi-lateral lying is more difficult to define accurately. This was included as lateral lying, but the heavily-pregnant cows appeared to spend the majority of their lying time in this state.

After the first year of analysis of calving behaviour it was decided that the duration of tail raising may be important because counting the frequency alone missed changes in cows who held their tail up for longer durations before calving. For this reason, a new "tail down" state was added which was mutually-exclusive to "tail raise" which also became a state.

Chapter 3: Trends in calving records at Langhill Farm

Modern dairy farms keep detailed records about each cow in the herd. These are normally stored in a computer database which can easily be searched for specific information and include insemination dates, drying off dates and predicted calving dates (Rutherford, 2000).

The predicted calving dates are a simple projection of the time from the insemination dates, but the records contain a wealth of additional information that could potentially be used to increase the accuracy of this prediction.

It is also possible that the individual data stored could help predict increased risks of problems during the transition period.

These topics will be examined separately in two parts of this chapter. Part 1 will discuss calving prediction and Part 2 will describe analyses of some potential risk factors associated with problems during the transition period.

3.1 Part 1: Calving prediction

3.1.1 Introduction

The current method of calving prediction is based on the average gestation length for Holstein-Friesian cows. The average gestation length is added to the insemination date to give the predicted calving date, providing an indication of when each cow should be dried off and when she is likely to calve. Once cows are within two weeks of their predicted date, stockmen use visual observations to assess when they are close to calving. Signs such as swelling of the udder, relaxation of the pelvic ligaments and restless behaviour are used for these observations.

This system is straightforward and provides a suitable estimate for management purposes, in terms of the weeks before calving, but provides only a rough approximation of the actual date. If variables from the farm database, such as parity or sire, are associated with differences in gestation length these may be useful for making minor adjustments that could improve the accuracy of predicted calving dates.

If the likelihood of calving during the night or day could be estimated, this may allow for helpful adjustments to management to be made. On some farms there are more calvings during the day (Yarney *et al.*, 1982) and differences in time when calving occurs are associated with calf weights (Tharmaraj *et al.*, 1989) and feeding times (Lowman *et al.*, 1981).

The methods used by stockmen to predict the onset of calving are also of interest. The physical and behavioural signs that they use and the length of time before calving that they can observe them, within the hours before calving, may provide useful information regarding important behavioural changes that should be investigated and the time scale over which they are seen.

3.1.1.1 Research aims

The aim was to identify any variables from the calving records that could be used to predict calving. More specific research aims used to present the analyses are listed below.

1. To examine variables related to variation in gestation length to identify any that could be used to help improve the accuracy of predicted calving dates.

2. To examine variables associated with variation in the time of day of calving to identify any that may be useful to help predict if calving is more likely during the day or night.

3. To summarise the signs of calving recorded by stockmen to establish the behaviours they use to predict calving, and study any differences between the signs noticed before assisted and unassisted calvings and between heifers and cows.

4. To investigate when stockmen notice the first signs of calving to give an indication of when visible changes occur and allow comparison with behavioural observations from video recordings.

3.1.2 Methods

The farm records described in the methodology chapter were analysed for this part of the study. A general linear model (GLM) was run to look for factors that had a significant effect on the gestation lengths of cows. The factors included in this model were the month of calving, parity (cow or heifer), sire, single or twin, calf survival and calf sex. Interactions between these variables were also included in the model. To look for any consistency in gestation length between years, the values for cows that were in both years of the study (n = 91) were used to calculate a linear regression between gestation lengths in the first and second year.

The number of calvings during the day (06:00-18:00) and night (18:00-06:00) were compared between the two years and checked for any consistency between years in the same cows using chi-squared tests. Chi-squared tests were also used to examine potential differences in the number of night and day calvings between months, parities, single and twin calvings, live and dead calves and between calf sexes.

The number of times each first sign of calving was recorded by the stockmen was tallied. When a stockman noted more than one sign per cow, all of them were counted. The totals for cows and heifers with unassisted and assisted calvings were compared using a chi-squared test. The cases when the calf was born or calving had already started were not included in the analysis because these are not predictive signs of calving.

The time from when the first signs were noticed until the calf was born were classified as ordered categories (0-1 h, 1-2 h, 2-3 h, 3+ hours before calving) and compared between cows and heifers with assisted and unassisted calvings using a chi-squared test. To show when each sign of calving was observed and with what frequency, each was plotted onto an individual graph showing the counts for each time period before calving. All means are given with their standard deviation and medians with their inter-quartile range (IQR), unless stated otherwise.

3.1.3 Results

3.1.3.1 Variables related to gestation length

Gestation lengths that deviated more than 14 days from the average of 282 days were excluded from the analyses to ensure that the insemination dates in the records were accurate. This should have excluded any cows that conceived at a previous or later service than entered in the records, leaving data with a normal distribution (Figure 3.01).

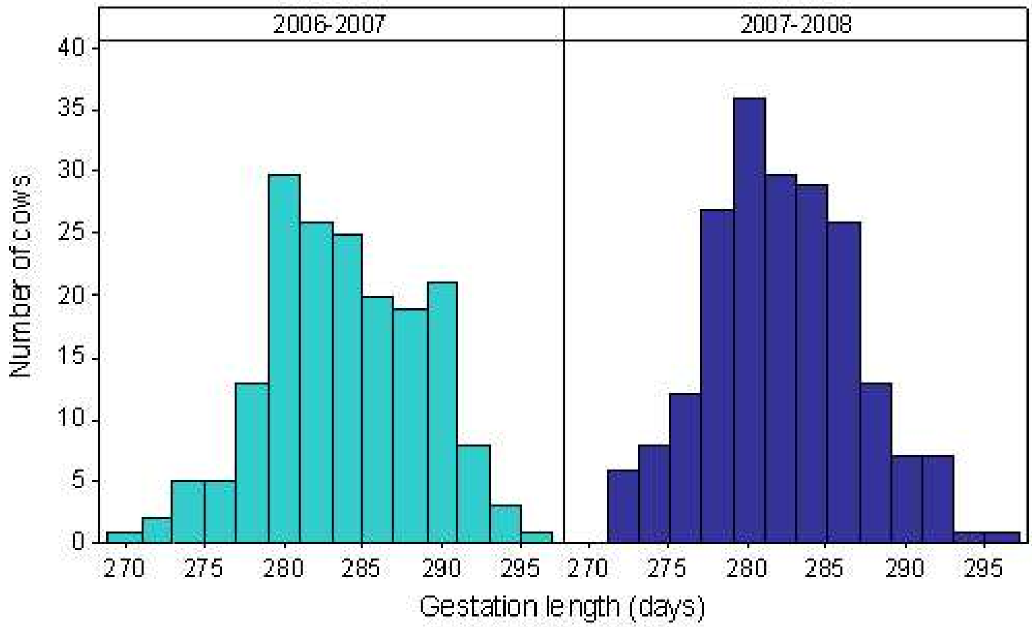

Figure 3.01
Gestation lengths of cows calving at Langhill Farm in 2006-2007 (left) and 2007-2008 (right). The means and ranges were similar between the two years.

Six factors were tested against gestation length in a GLM so the independent effect of each variable could be determined. Calf survival ($F_{1,247} = 0.12$, $p = 0.726$) and calf sex ($F_{1,248} = 0.35$, $p = 0.555$) were not significant. However, all of the other factors had significant main effects on gestation length. Seasonal differences in gestation length were shown by the significance of month as a factor ($F_{9,273} = 2.14$, $p = 0.026$).

The shortest gestation lengths were found in August (275.1 ± 3.8 days, n = 7) and gradual increases were seen each month until the longest gestation lengths were recorded in May (284.7 ± 5.1 days, n = 6) (Figure 3.02).

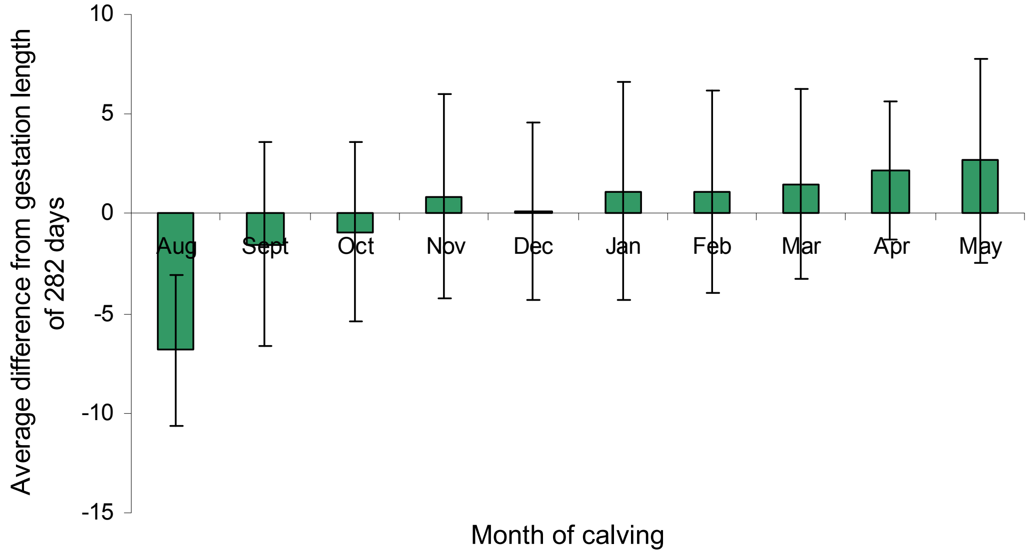

Figure 3.02
Gestation lengths of cows and heifers at Langhill Farm for each month of the calving season are shown as deviations from the expected average. Gestation lengths were shorter in August and increased each month to a maximum in May.

Parity was included as a two-level factor with primiparous individuals classed as heifers and multiparous individuals as cows. This had a significant main effect on gestation length ($F_{1,273}$ = 11.02, p = 0.001). Heifers had significantly shorter gestation lengths (281.03 ± 4.98 days, n = 111) compared with cows (283.22 ± 4.85 days, n = 180).

Dams that were artificially inseminated using beef semen or mated to a beef bull had longer average gestation lengths (284.5 ± 4.4 days) than those inseminated with dairy semen (281.5 ± 5.0 days). This difference was highly significant ($F_{1,273} = 12.97$, $p < 0.001$) and the data appear to form two separate normally-distributed groups, although the ranges are similar (Figure 3.03).

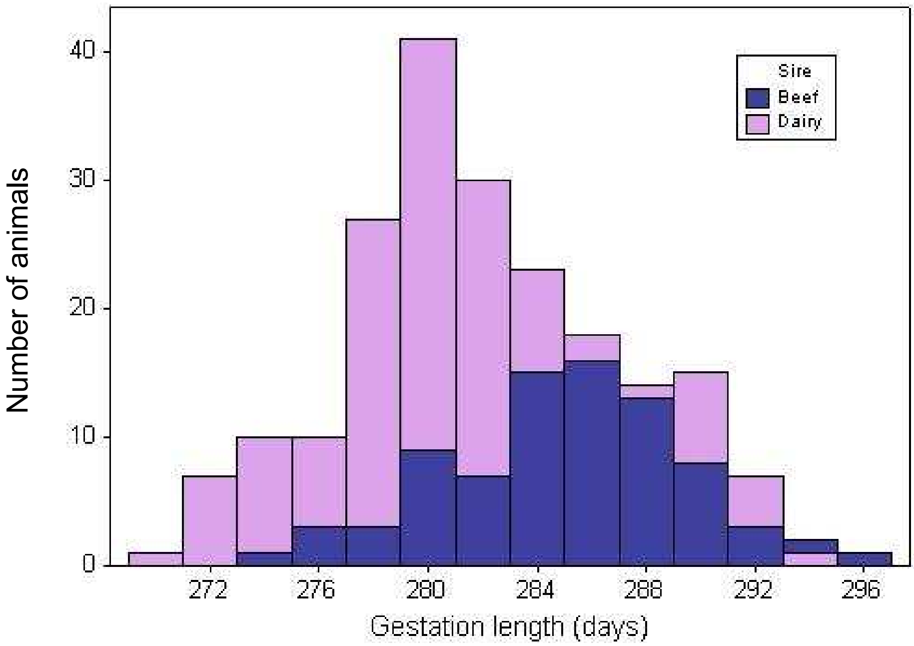

Figure 3.03
Histogram showing the gestation lengths of cows and heifers that were mated to beef (dark blue) and dairy (purple) sires. For beef calves the median gestation length was 285 days (IQR = 282-288 days) and for dairy calves the median was 281 days (IQR = 278-285 days).

The mean gestation length of twin calves (n = 17) was 278.8 ± 5.2 days and was significantly shorter than the mean gestation length for single births (n = 274), which was 282.6 ± 4.9 days ($F_{1,273} = 20.69$, $p < 0.001$).

The regression between gestation lengths in the first year of the study against the gestation lengths the next year suggested that there may be some tendency for gestation lengths to be similar in later years. This trend is shown in Figure 3.04, although it was not significant at the 95% level ($F_{1,89} = 3.68$, $p = 0.058$).

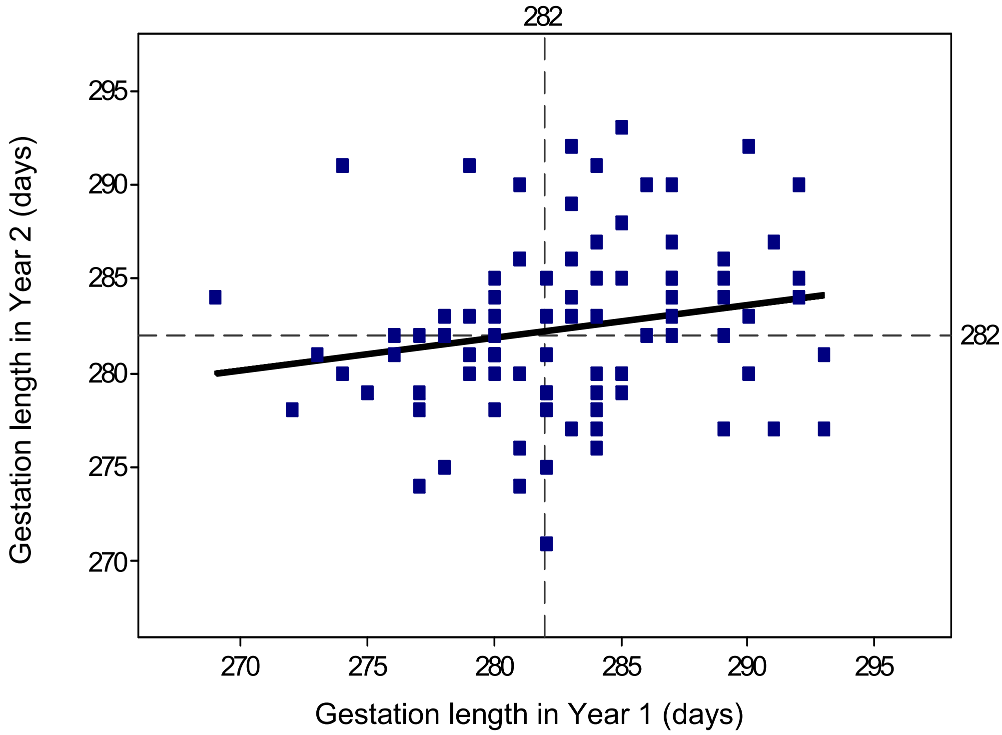

Figure 3.04
Scatter plot showing the regression between gestation lengths in the first year of the study and those in the following year. The trend between these was not statistically significant and there was a lot of individual variation.

3.1.3.2 Variables associated with time of day of calving

The distributions of the times of day when cows and heifers calved during the two years covered in this study are shown in Figure 3.05.

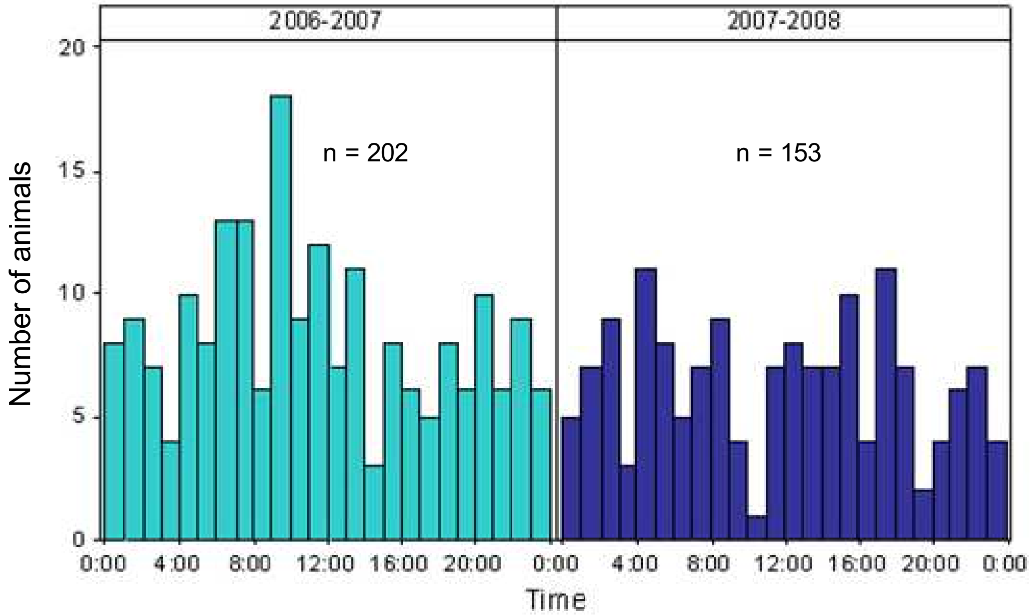

Figure 3.05
The times of day when cows and heifers calved at Langhill Farm during the two calving seasons. For twin calves, only the time of the first was included.

There was no difference between the proportions of animals that calved during the day (06:00-18:00) or night (18:00-06:00) between the two years of this study (X^2 = 1.01, df = 1, p = 0.316).

The time of calving was recorded for 100 cows present in both years of the study. If this was independent between years, half of the cows would be expected to have one calving at night and one in the day time, and the remaining half would be split between having both calvings during the night and both during the day. The observed situation was very close to this, with 53 cows calving once in the day time and once during the night, 21 cows with both calvings at night and 26 cows with two day time calvings. This was not significantly different from the expected proportions (X^2 = 0.031, df = 1, p = 0.861) so calving time was assumed to be independent between years and both records for these 100 cows were included in the dataset.

Changes in the time of day of calving during different months were tested to see if there were any seasonal effects. Results for August and September, and April and May, were grouped to make the sample sizes large enough to study. No significant effect of season was observed when the number of calves born during the night and day were compared (X^2 = 6.299, df = 7, p = 0.505).

Parities from seven upwards were grouped to look for differences in the time of day of calving (night or day) between parities but no significant result was found (X^2 = 5.630, df = 6, p = 0.466). Twins were also equally likely to be born during the day as during the night (X^2 = 0.493, df = 1, p = 0.483), and no significant difference was found between the number of live and dead calves born during the day and night (X^2 = 0.098, df = 1, p = 0.754).

The factor closest to showing a significant association with calving at day or night was the sex of the calf. There was a tendency for more bull calves to be born at night (88 compared to 73 during the day) and more heifer calves born in the daytime (101 compared with 85 at night). However, a lot of data were missing and these results were not significant (X^2 = 2.771, df = 1, p = 0.096).

3.1.3.3 Signs of calving recorded by stockmen

These observational records were made for a total of 406 cows and heifers. The signs of calving were condensed into ten categories and the number of times each was reported was counted for unassisted and assisted calvings, in cows and heifers (Table 3.01).

Table 3.01 First signs of calving identified by stockmen

First sign of calving	Cows		Heifers	
	Unassisted (n = 185)	Assisted (n = 107)	Unassisted (n = 19)	Assisted (n = 95)
Calf born	91	-	12	-
Started calving, i.e. water bag or part of calf seen at vulva	25	43	0	47
Straining/pressing	12	11	2	9
Tail up	58	58	4	45
Uneasy/restless	11	14	1	6
Bloody discharge	5	4	1	5
Slimy discharge	6	6	0	1
On own/not getting up to feed	6	3	0	5
Vocalisation	0	2	0	0
Calf stealing	1	0	0	0
Total number of signs	215	141	20	118

Vocalisation and calf stealing were omitted from the analysis because of their low counts. The counts for assisted and unassisted heifers were combined because of the low numbers of unassisted individuals. The proportions of signs observed before calvings in unassisted cows, assisted cows and heifers were not significantly different from each other (X^2 = 7.377, d.f. = 10, p = 0.693). The frequencies of observation of each of the signs are shown in Figure 3.06.

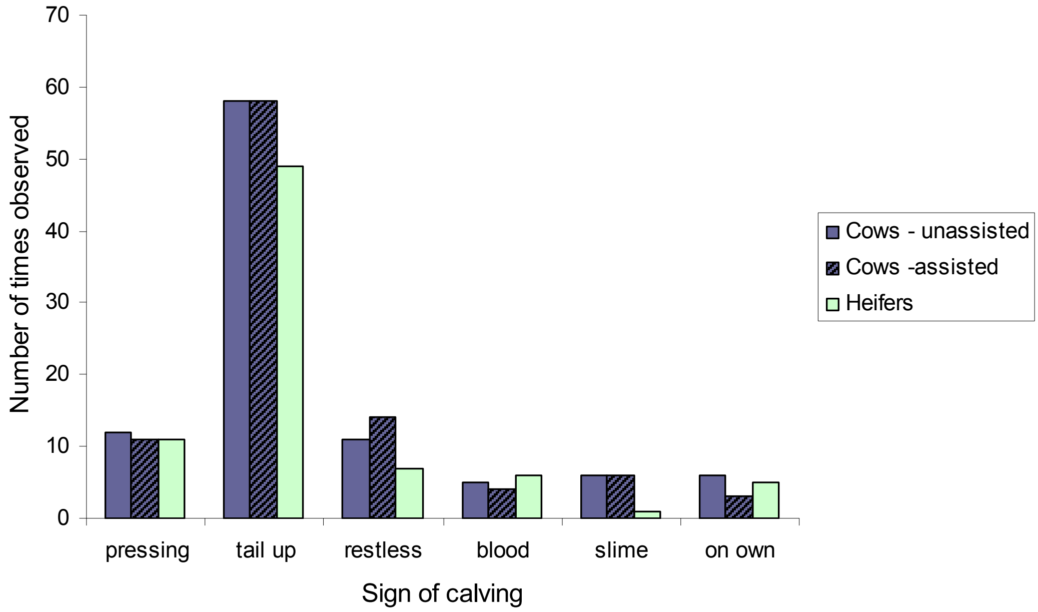

Figure 3.06
The number of times different signs of calving were noticed in assisted cows, unassisted cows, and in heifers.

3.1.3.4 When stockmen notice first signs of calving

The times from when the first sign of calving was noted until the calf was born were also summarised separately for cows and heifers that had unassisted and assisted calvings (Table 3.02).

Table 3.02 Number of calvings in relation to the time when the first sign of calving was identified, summarised for cows and heifers, and unassisted or assisted calvings

Time between first sign and calving	Cows		Heifers	
	Unassisted (n = 185)	Assisted (n = 107)	Unassisted (n = 19)	Assisted (n = 95)
0h (calf found)	91	-	12	-
0-1h	31	37	0	39
1-2h	34	30	5	22
2-3h	17	30	1	16
3-4h	7	7	1	10
4-6h	4	1	0	6
>6h	1	2	0	2

The values for 0 h (calf found) and 0-1 h were combined for the chi-squared analysis because these can both be presumed to be when calving has already started. The longest three classes of time (3-4 h, 4-6 h and >6 h) were also combined because of their small sample sizes. There was a significant difference between the times when unassisted and assisted calvings in cows and heifers were noticed (X^2 = 44.521, d.f. = 9, $p < 0.001$).

The numbers in Table 3.02 were calculated as percentages of the total number of observations and are illustrated in Figure 3.07.

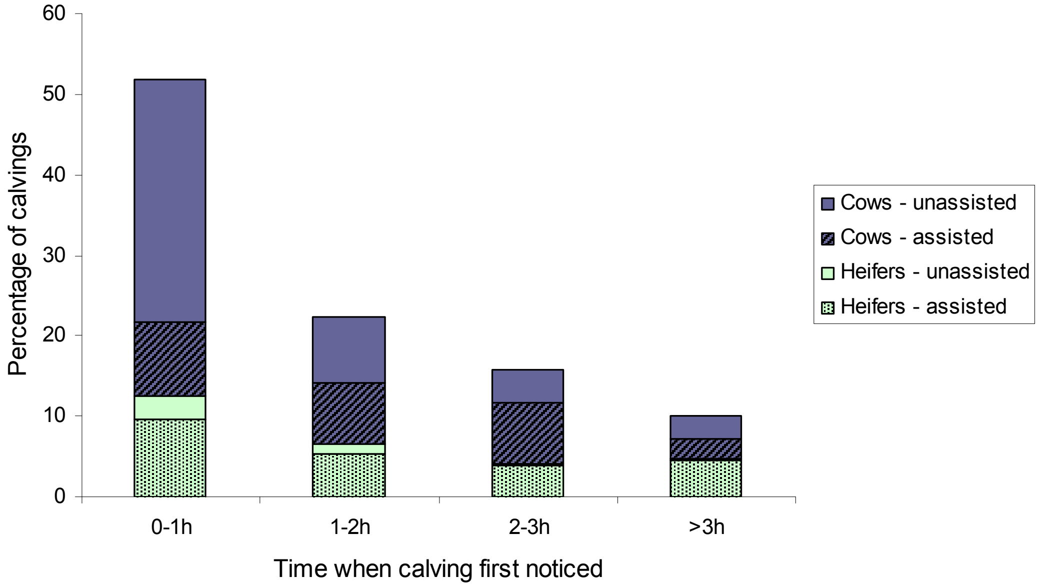

Figure 3.07
The percentage of assisted and unassisted calvings noticed at various times before the calf was completely expelled, in cows and heifers. Assisted heifers were noticed from four hours or longer before calving more often than expected and assisted cows were often noticed from 2-3 hours before. Within the cows, unassisted calvings were most often noticed during the final hour before calving or after calving had happened, whereas those that were assisted were frequently noticed to show signs of calving 2-3 hours before they were assisted.

To combine the information provided from the observations of the stockmen, the times when each of the signs was noticed before calving were summarised for assisted and unassisted calvings. In many cases, dams had already started to calve. Various signs were described at this point but the sign shown separately here is when the calves' feet were showing (Figure 3.08).

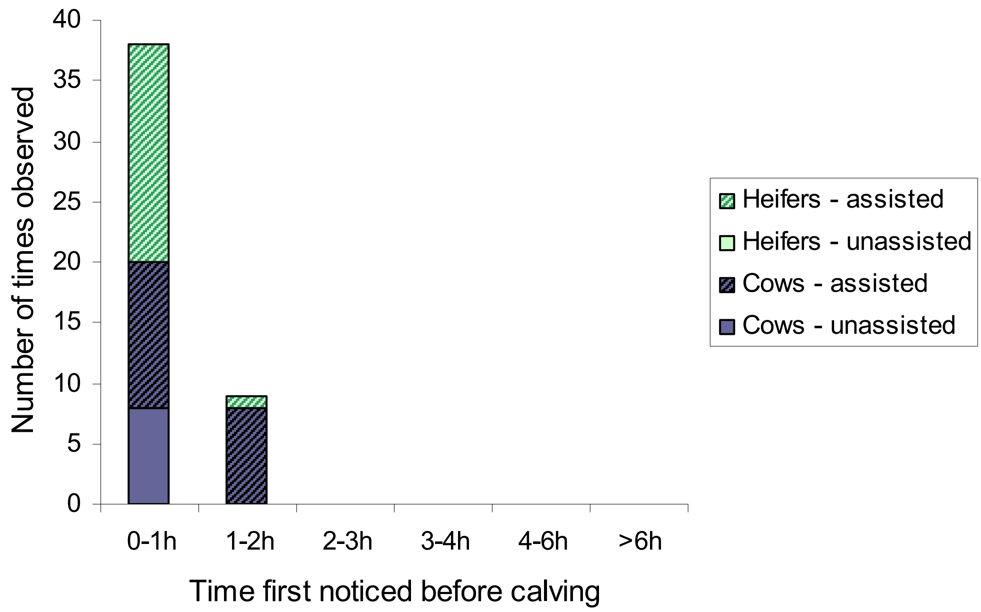

Figure 3.08
The number of times calves' feet were seen within various times before calving. Individuals were always assisted within two hours after this was observed. Only a relatively small number of dams calved unassisted within an hour after the feet were seen.

Straining or pressing was observed longer before calving in cows and heifers that were assisted than those that calved without any intervention (Figure 3.09).

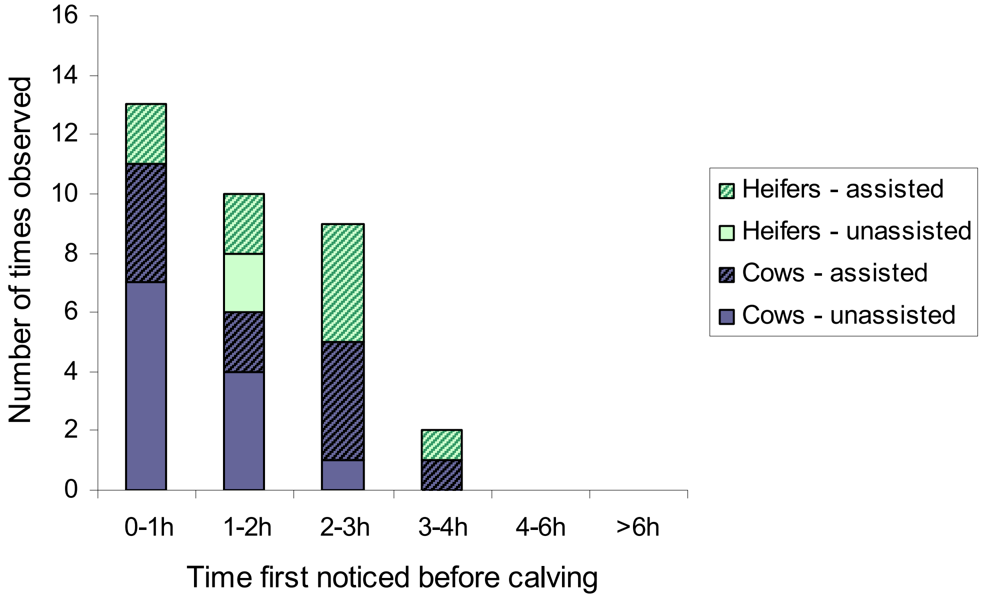

Figure 3.09
The number of times straining was observed within various times before calving. This sign of calving was first observed within four hours for assisted individuals, and three hours for those that calved unassisted.

Tail lifting was the most frequently observed sign of calving and was also observed earlier in assisted individuals (Figure 3.10). The peak in observations of tail raises happened within three hours of calving for assisted cows and heifers. In unassisted cows and heifers the peak in observations was within the final two hours.

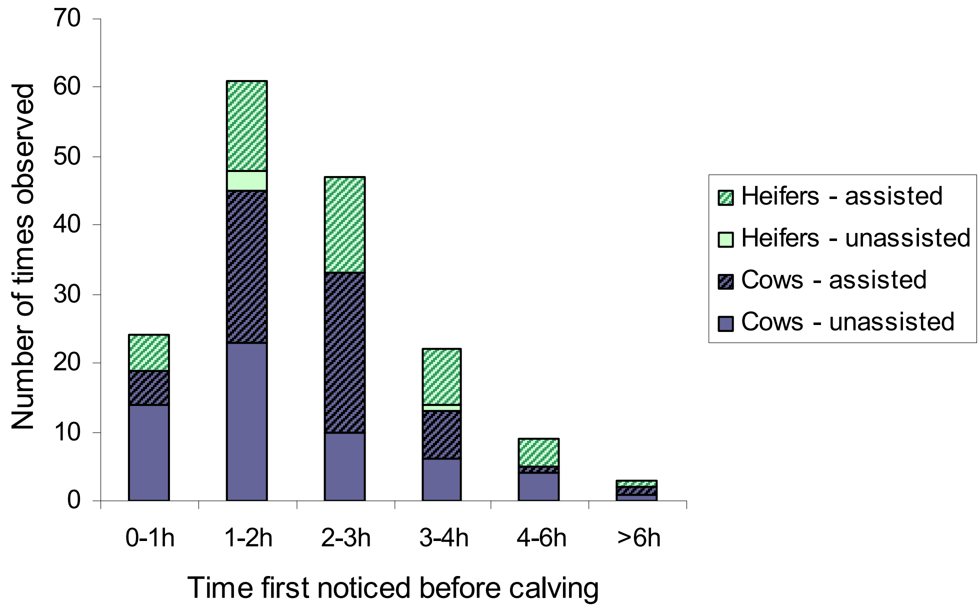

Figure 3.10
The number of times tail lifting was observed within various times before calving. This sign of calving was observed earlier in assisted individuals, from longer than six hours before calving. The peak in observations of this behaviour was also longer before calving for assisted animals, compared with those that calved without assistance.

Restlessness was observed more often and noticed earlier in cows and heifers that were assisted that those that were not assisted (Figure 3.11).

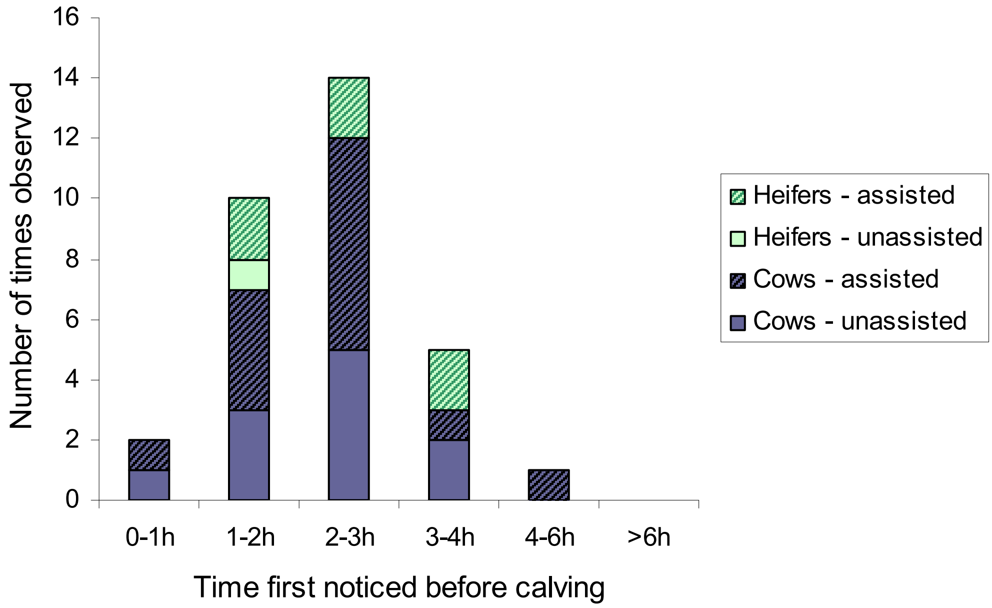

Figure 3.11
The number of times uneasy or restless behaviour was observed within various times before calving. This was noticed as a sign of calving mainly within the last four hours before calving. Most observations of this behaviour were made 2-3 hours before calving.

Blood and bloody discharges were not observed very frequently before calving but were more commonly seen in cows and heifers that were assisted (Figure 3.12).

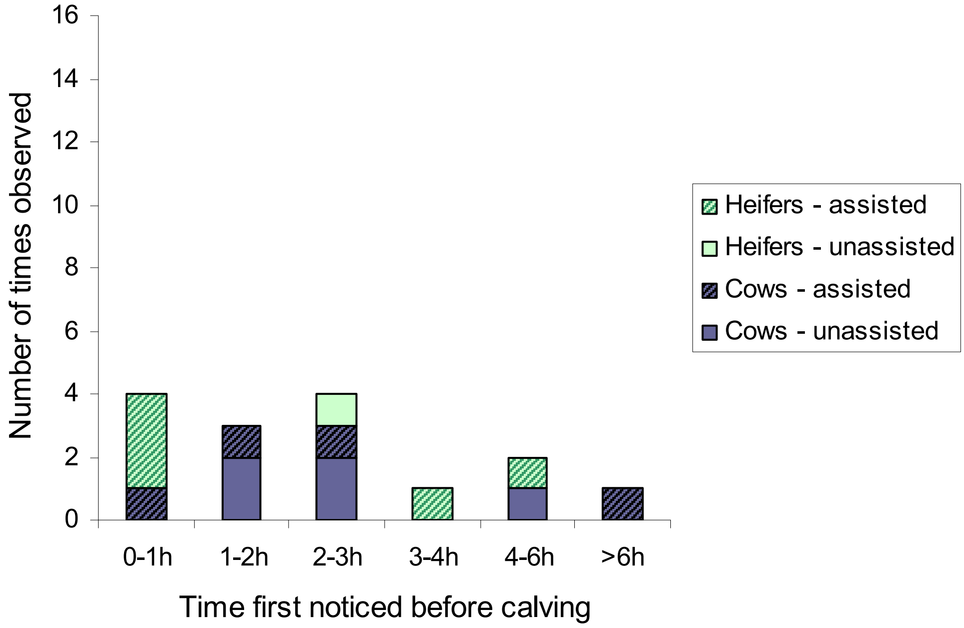

Figure 3.12
The number of times bloody discharges were observed within various times before calving. This was observed from over six hours before calving in one cow, but was mainly seen in the final hour (assisted) or three hours (unassisted).

Slimy mucus discharges were seen almost equally in assisted and unassisted cows during the final four hours before calving and this sign of calving was only observed in one heifer (Figure 3.13).

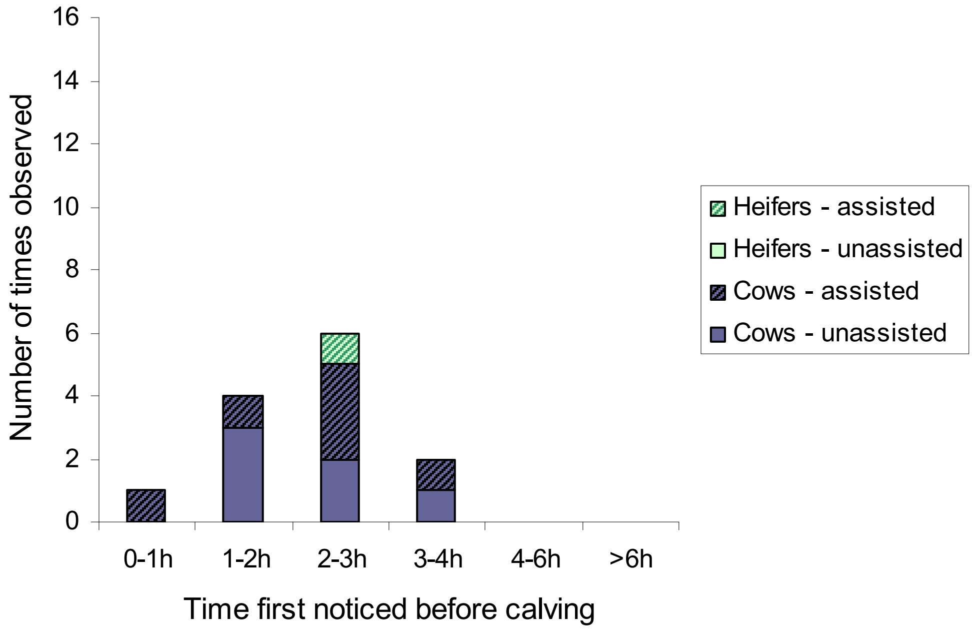

Figure 3.13
The number of times slimy discharges were observed within various times before calving. This sign of calving was not observed in many animals and showed a similar pattern for assisted and unassisted cows.

Not getting up to feed and standing or lying separate from the other animals in the shed was not seen very often but appears to have been noticed earlier in cows that were assisted, and only in assisted heifers (Figure 3.14).

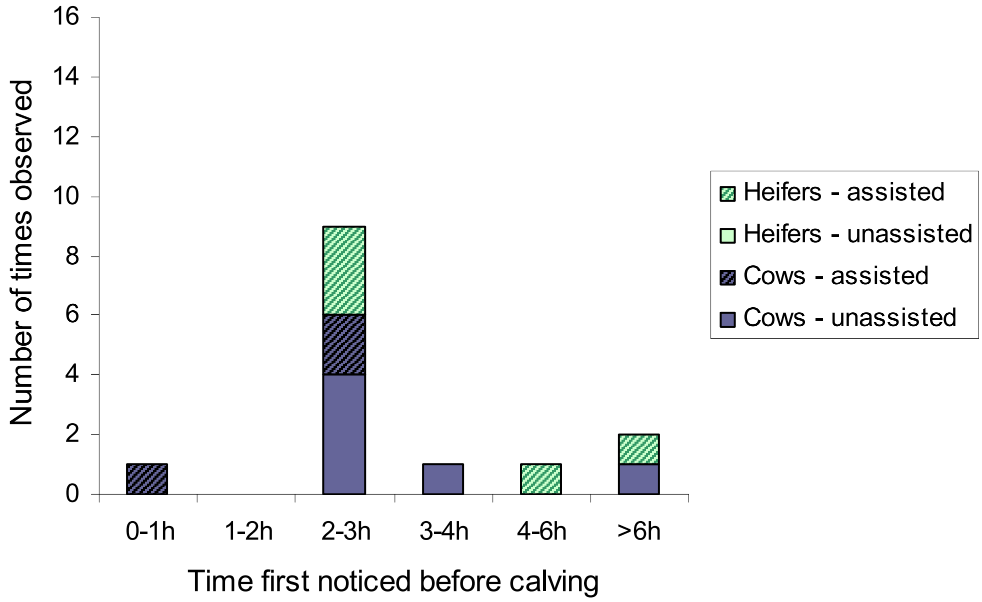

Figure 3.14
The number of times an individual being on her own or not getting up to feed was observed within various times before calving. This was most often noticed 2-3 hours before calving.

3.1.4 Discussion

3.1.4.1 Variable related to gestation length

The gestation lengths of cows were normally distributed during both years of the study. As most of the variables were tested for significance in a single general linear model, the independent effect of each could be shown. The mean gestation length for each year was close to the expected duration of 282 days for Holstein-Frisian cows (Fisher and Williams, 1978). Gestation lengths increased in duration as the calving season progressed, with the shortest average in August and the longest in May. The difference over these ten months was gradual but amounted to an overall difference of 9.6 days, meaning that gestation lengths increased in duration by approximately one day per month, independent of the other factors included in the model. Similar seasonal differences in gestation lengths have also been observed in other studies (Fisher and Williams, 1978; Bleul, 2008).

Heifers had shorter gestation lengths than cows by an average of two days. Other studies have also reported differences (Crews, 2006) and a difference of 2.2 days was specified by Bleul (2008) which suggests that this is a general trend amongst dairy cows. Echternkamp and Gregory (1999) also reported gestation lengths that were two days shorter in beef heifers.

Longer gestation lengths were observed in cows that were mated to beef sires, compared with dairy sires. The median for dairy calves was close to the expected average of 282 days for Holstein-Frisian cows, at 281 days. Beef breeds are known to have longer average gestation lengths (288 days for Limousin and 283 days for Hereford-Angus) than dairy breeds so this difference was expected (Smith *et al.*, 1976).

Twins had shorter gestation lengths by an average of 3.8 days. This is in agreement with other studies (Bleul, 2008) but not as large a difference as reported in beef cattle where twins had shorter gestation lengths of 275 days compared to 281 days for single calves (Echternkamp and Gregory, 1999).

Gestation lengths were not significantly correlated between years, although there may have been a trend suggesting that there could be a genetic component contributing to the variation in gestation lengths. However, there are many other variables that may have an influence and result in a lot of variation.

There were no significant differences between the gestation lengths of healthy calves and those that died within two days after birth. However, the data were edited to only include those calves with relatively normal gestation lengths so any potential difference may have been hidden. Hansen *et al.* (2004a) showed a clear non-linear association between stillbirths (calves died within first 24 hours) and gestation length, with high mortality in calves with short and long gestation periods. In their study the gestation lengths ranged from 256-300 days (compared with 269-296 days in the current study). High mortality was observed for calves with gestation lengths shorter than 265 days and longer than 294 days.

No difference in the gestation lengths of male and female calves was found. However, the literature suggests that in some cases male calves have longer gestations. In one study male calves had an average of 1.7 days longer gestation time than females (Fisher and Williams, 1978) and in a study of beef calves males had gestation lengths that were an average of 1.3 days longer than female calves (Crews, 2006).

The month of calving, parity and sire are all known from the farm records and could be used to adjust the predicted calving dates. However, the largest difference in gestation length is seen between twins and single calves. As it is not always possible to tell if a cow is going to have twins, any adjustments made will never be completely accurate and cows will still need to be carefully observed from at least a week before their predicted calving date.

3.1.4.2 Variables associated with time of day of calving

The distribution of calving throughout the day did not seem to follow any pattern or be more concentrated during the day or night. A study of the hourly distribution of calving in beef cows also found a fairly uniform distribution over 24 hours although there was a slight bias (51.5%) towards calving during the day, between 07:00 and 19:00 (Yarney *et al.*, 1982). Pennington and Albright (1985) fed cows at night to see if this would result in a higher proportion of calvings during the day (06:00-18:00) but no significant difference was seen between the night-fed and control groups. However, they did observe that there were significantly more calvings during the day than the half expected (62.5% and 67.6% in the control and night-fed groups, respectively). The cows in this study had feed available throughout the day and night so the effect of feeding time could not be assessed.

It would have been more appropriate to compare daylight with darkness, instead of arbitrarily splitting day and night into two 12-hour periods. This was done by Edwards (1979) but no difference was found between the number of calvings during daylight and darkness, even though a large sample size of 522 calvings were observed.

There were no between-parity differences in the time of day when dams calved most frequently. This agrees with the results of other studies of both dairy (Pennington and Albright, 1985; Tharmaraj *et al.*, 1989) and beef cows (Yarney *et al.*, 1982).

The number of dairy and beef calves born during the day and night was not analysed in this study. No differences in the time of birth of calves from different beef sire breed types were found in a study by Yarney *et al.* (1982) but they did find results suggesting that there may be some influence of the maternal grandparents on the time of calving.

Calf weights were compared by Pennington and Albright (1985) and no significant difference was found between dairy calves born during the day and those born at night. Yarney *et al.* (1982) also found no significant difference in a study of beef calves but Tharmaraj *et al.* (1989) reported that most of the lightest dairy calves in their study were born during the night (06:00-18:00).

The tendency for more bull calves to be born at night was not statistically significant. Other studies did not find any difference in the sex ratios of calves born during the day and night so there is no evidence to suggest that there may be a real difference (Pennington and Albright, 1985;Yarney *et al.* 1982; Tharmaraj *et al.*, 1989).

The results obtained in this study show general agreement with results reported in the existing research literature. The conclusion from this and other data is that none of the variables studied can helpfully predict if a cow is more likely to calve during the day or during the night.

3.1.4.3 Signs of calving recorded by stockmen

The same four stockmen worked on the farm and were involved with the monitoring of transition cows throughout the duration of this study, and the number of calvings attended or assisted by each was similar between the two years. This means that the results from the two years should be comparable and were analysed as a single dataset.

The signs used by the stockmen to predict calving could be grouped into ten types. Many of the calvings were not observed and only noticed once the calf had been born and many were noticed when parturition had started and the water bag or parts of the calf were visible. Observations of pressing or straining were recorded on a number of occasions and would also suggest that parturition had already begun.

In 47 dams, the feet of the calf were showing when calving was first observed. One cow was also vocalising so was assisted within an hour. In total, out of the 28 multiparous cows, eight calved within an hour without any assistance and the rest were assisted (12 within an hour and eight within two hours). All of the 19 heifers were assisted (18 within 1 hour and one within 2 hours). As the records kept were only short notes, it is hard to determine exactly how decisions to assist were made but the time from the feet showing is sometimes used in assistance protocols. In one study the protocol for assistance was to wait for two hours from when the calf's feet are seen and assist if no progress is seen during this time (Johanson and Berger, 2003). Similarly, in Wehrend *et al.* (2006) dams were given a vaginal examination and offered assistance if no progress in calving was observed two hours after the water bag burst. These references suggest that some of the assisted calvings in this study may have been completed naturally, if given more time.

The most commonly observed sign that was seen before the onset of parturition was the tail being raised. Tail raising and waving is commonly seen within the final day before calving (Wehrend *et al.*, 2006) and is associated with the first, preparatory stage of parturition (Phillips, 2002). Uneasy or restless behaviour was also noted fairly often, which is another sign reported in the literature (Huzzey *et al.*, 2005). Restlessness can mean a number of different things and is a fairly subjective term although it is consistently reported. Phillips (2002) gave a description which included regular head turning, frequent alternation between lying and standing, and interrupted eating patterns. Tail raising and restlessness were the most common signs which were noted, but there were also a number of others.

Less frequently observed signs of calving included slimy or bloody discharges, vocalisation and calf stealing. Not getting up to feed, and standing or lying separately from other cows in the shed was also considered as a sign of approaching parturition. Both vocalisation and separation from the herd were reported by Lidfors *et al.* (1994). The stockmen were not given any definitions of signs to use, so it is interesting that the signs which they noted show strong agreement with those reported in the research literature. Some differences were expected in the signs observed for cows that received assistance and those that did not, and between cows and heifers, but this was not observed. Wehrend *et al.* (2006) used an extensive list of behaviours to examine differences in behaviour during the first stage of dystocic and normal calvings, and between cows and heifers. The differences found were that a higher proportion of cows with dystocia rubbed against the wall, discharged urine and scraped the floor. A lower proportion of heifers showed calm behaviour compared to cows and a higher proportion of heifers pawed with their forefeet.

3.1.4.4 When stockmen notice first signs of calving

The time before calving when the signs were noted was examined separately for assisted and unassisted calvings because the duration before calving for assisted cows was partly dependent on the decision made by the stockman regarding when to intervene. Cows and heifers were also compared separately to look for differences in behaviour, or the decisions made to assist them. The majority of dams were noticed at a point when they had calved or were calving. More assisted than unassisted calvings were noticed longer than two hours before the calf was born. This could result from those that needed assistance taking more time to calve and therefore showing changes earlier or could be that these are the cows that have been noticed and given assistance as a result of this. Of the unassisted dams, heifers were observed as showing signs of calving earlier than multiparous cows, with proportionately more heifers observed from 1-2 hours before calving and most cows within the final hour before calving. Most assisted heifers were noticed more than three hours before calving and assisted cows within three hours. This does not agree with the results of a study of beef cattle in the United States that found that cows were allowed to spend longer in labour before assistance was given than heifers. Labour is naturally longer in heifers than in cows so prolonged labour in cows is more indicative of a severe problem that will not respond to ongoing attempts to calve (Dargatz *et al.*, 2004).

The duration before calving when each sign was observed was summarised for each individual sign. Most of the signs were observed earlier before calving in assisted cows, as was expected because cows with longer calvings are more likely to be assisted. Few signs were noticed more than four hours before calving, suggesting that most of the changes that can be observed by the stockmen only occur within these final few hours before calving. Pressing or straining was only observed from four hours before calving and within three hours of calving for assisted dams. Tail raising was seen at a wide range of different times before calving with the peak from 1-2 hours before. Most uneasy or restless behaviour was observed from 2-3 hours before calving and was always seen within six hours before calving (and within four hours before in heifers). The observations of bloody discharges did not show any patterns and the numbers of times this was seen was fairly small. Slimy discharges were seen more often, within four hours of calving and more frequently in cows than heifers. Separation from the herd or not getting up to feed was mainly seen more than two hours before calving.

3.2 Part 2: Some risk factors for problems during the transition period

3.2.1 Introduction

The following problems during the transition period; assistance required at calving, calf mortality, extended calving intervals, and milk fever; will be discussed in this chapter. Any risk factors for these problems that are identified could be used to help recognise cows that are at increased risk and ensure that these individuals are carefully monitored.

The relative risk of different conditions in dairy cows is thought to be related to the following variables. The need for assistance at calving has been shown to vary with season (Johanson and Berger, 2003) and the time of day (Yarney *et al.*, 1982). Heifers require assistance more frequently than cows during their second or subsequent calving (Lombard *et al.*, 2007; Bleul, 2008). Twin calves (Echternkamp and Gregory, 1999), male calves (Bleul, 2008) and heavier birth weights (Johanson and Berger, 2003) are also variables that increase the risk of the cow requiring assistance.

Calving difficulty can result in increased calf mortality. Variation in the incidence of calf mortality as a result of dystocia is associated with season (Johanson and Berger, 2003), parity, calf sex, calf mortality at previous calvings (Mee *et al.*, 2008) and twinning (Lombard *et al.*, 2007). Twins that are identical or result from two ovulations in the same ovary begin development in the same uterine horn, increasing the chance of loss due to overcrowding unless one migrates to the other horn. As the foetal membranes of twin calves tend to fuse there is a direct vascular connection between the two. This means that if one calf dies, it is likely that the other will also die (Ball and Peters, 2004).

The duration of an individual's calving interval is a combination of the time taken to begin cycling following calving, the number of cycles taken to conceive and gestation length. Calving intervals may be extended following problems during calving as the onset of ovulation can be delayed or the chance of conception lowered. When cows experience extreme calving difficulty, this can extend the number of days open before the cow conceives her next calf. Dematawewa and Berger (1997) found that cows that required minor assistance had an average of seven extra days open and this increased to 16 days and 33 days for those requiring considerable force and with extreme difficulty, respectively. The cost of this additional time until the next service contributed to 32% of the total costs resulting from calving difficulties. Longer calving intervals have also been reported following twin calvings (Echternkamp and Gregory, 1999) and cases of milk fever (Vacek *et al.*, 2007).

Milk fever is a relatively common metabolic problem in dairy cows during the transition period. The average incidence observed in 434 British dairy herds from 1998-2002 was 5.0% (Whitaker *et al.*, 2004). This is primarily a condition seen in older individuals from the third lactation onwards (Phillips, 2001) and repeat cases in the same cows are common (Calavas *et al.*, 1996).

3.2.1.1 Research aims

The aim of this part of the study was to identify any risk factors from the calving records associated with various problems during the transition period. The more detailed research aims are listed below.

1. To examine factors in the cows' records which might predispose cows to calving difficulty.

2. To identify potential factors associated with calving problems which might increase the risk of calf mortality.

3. To examine whether extended calving intervals were associated with poorer subsequent reproductive performance.

4. To identify potential factors in the calving records that could be used to identify individuals most at risk of milk fever.

3.2.2 Methods

The level of assistance was the first variable to be analysed for associations with a number of variables. Differences between months were examined using a chi-squared test. Gestation lengths and calf weights were compared between the different levels of assistance by ANOVA. Chi-squared tests were used to analyse the effects of time of day (day or night), parity, stockman, sire, twins, recurrence between years and calf sex on the level of assistance required.

Calf survival was scored as live or dead (including those that died within two days) so most comparisons were made using chi-squared tests. The variables compared were month, sire, twins, assistance and calf sex. The survival of calves from the same dams between the two years was also investigated.

Calving intervals were positively-skewed so non-parametric tests were used. The association between calving interval and gestation length was investigated using a Spearman's rank correlation. Parity differences between calving intervals were tested using a Kruskal-Wallis test, as were the difference between the levels of assistance at the calving that preceded the calving interval. All of the two-factor variables (sire, twins, calf survival and milk fever) were compared using Mann-Whitney U-tests.

The incidence of milk fever each month (number of cows given calcium) was calculated to show any seasonal effects but the number of cases was too small to conduct any further analysis on these data. The gestation lengths preceding cases of milk fever were compared with those of cows without milk fever using a two-sample t-test. Chi-squared tests were used to examine the possible influence of parity, sire, twinning, calf survival and assistance on the occurrence of milk fever. The recurrence rate of cases in cows in both years of the study was calculated. Calf weights from cows with and without milk fever were compared using a two-sample t-test. All means are given with their standard deviation and medians with their inter-quartile range (IQR), unless otherwise stated.

3.2.3 Results

3.2.3.1 Variables associated with assisted calvings

The calving difficulty scores were used to summarise the level of assistance received for most of the calvings in the two years. The information about each individual calf, including twins, is shown in Figure 3.15.

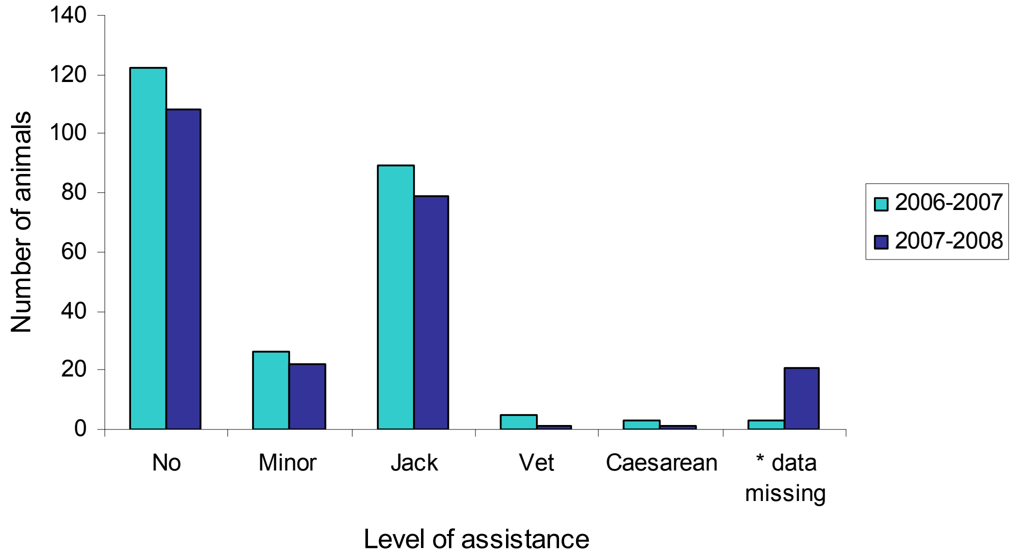

Figure 3.15
Levels of assistance during calving at Langhill Farm. Similar proportions were seen over the two years of the study, with approximately half of calvings unassisted. Assistance using a calving jack was more common than minor assistance by hand.

The number of assisted calvings was tallied for each month of the calving season to look for seasonal variations. These were simplified into assisted and not assisted, and data from August and September combined to give an adequate sample size. No significant changes were found between months in the proportion of assisted calvings ($X^2 = 8.944$, df = 8, p = 0.347).

As twin calves have the same gestation length their assistance score was combined such that it was classed as the highest assistance level, if either twin was assisted.

The average gestation length for unassisted calves was 282.5 ± 4.5 days (n = 173) and for assisted calves this was 282.3 ± 4.8 days for minor assistance (n = 44), 282.6 ± 5.0 days for jack assistance (n = 144), and 283.0 ± 8.1 days for calvings assisted by a vet (n = 6). The gestation lengths of unassisted and minor, jack or vet assisted calves were not significantly different ($F_{3,363} = 0.08$, $p = 0.971$).

For the times of calving, the time of the first twin was used and the highest level of assistance in a pair of twins used as their assistance score (unassisted, minor, jack or vet). There were significant differences in the levels of assistance seen at night and during the day ($X^2 = 10.00$, df = 3, $p = 0.019$). More unassisted calvings happened during the night and minor and jack-assisted calvings were both more frequent during the day (Figure 3.16).

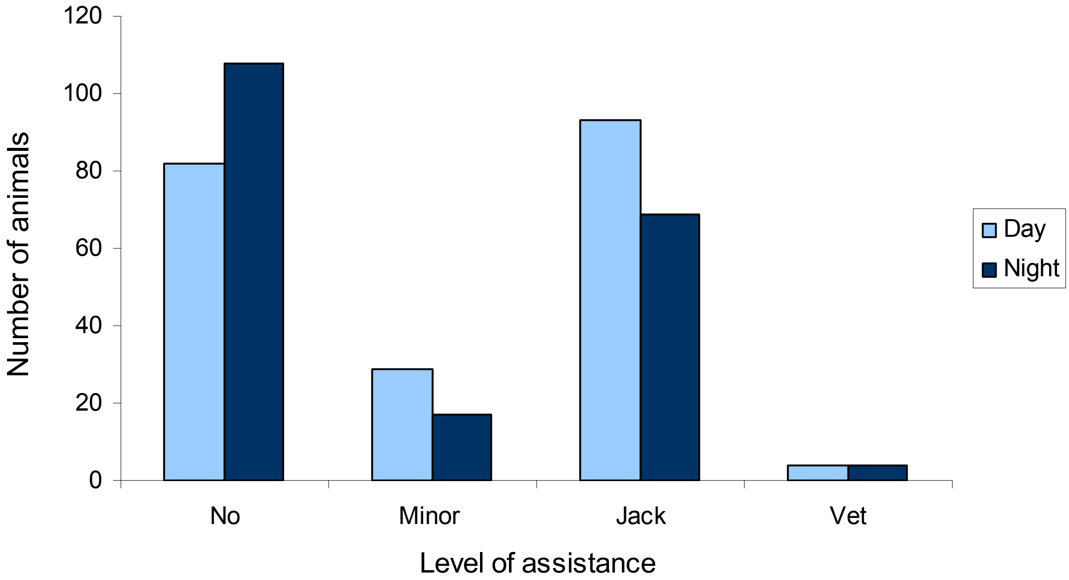

Figure 3.16
The degree of assistance given to cows and heifers during the day (06:00-18:00) and night (18:00-06:00). Vet-assisted calvings include caesarean operations. More calvings were unassisted during the night and more were assisted in the day time.

To test for the effect of parity, calvings were classed as assisted or unassisted and cows with parities of seven and upwards were grouped. Twins were grouped because the parity of the dam would be the same for each. Heifers (parity one) had significantly more assisted calvings than any other parity ($X^2 = 71.108$, df = 6, $p < 0.001$). This is shown in Figure 3.17.

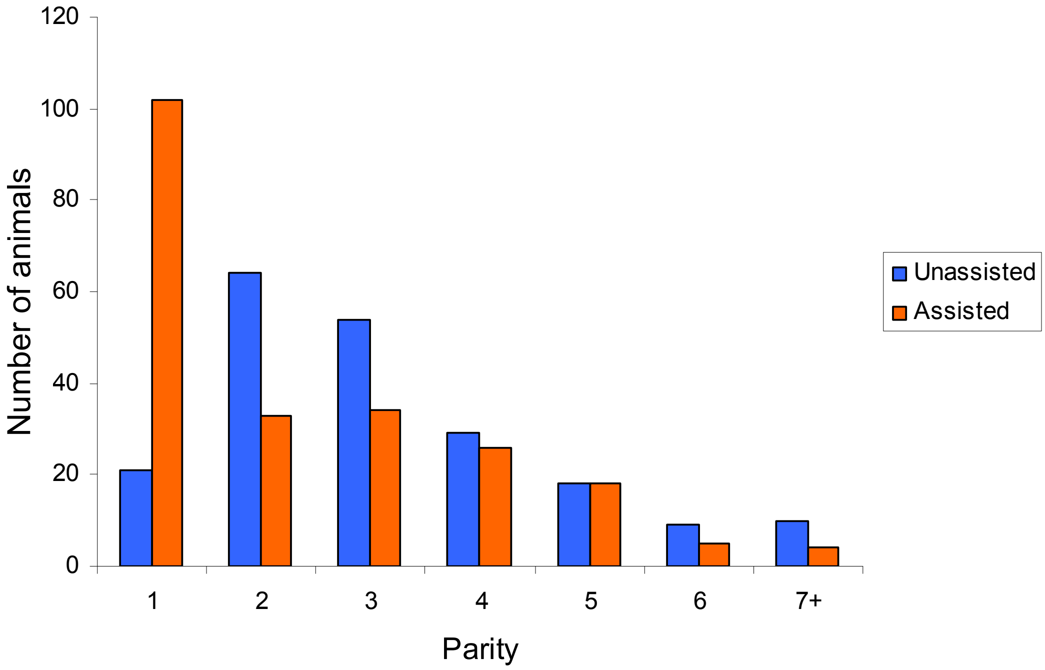

Figure 3.17
The number of assisted and unassisted individuals of different parities. Heifers (parity one) were assisted more frequently than any other parity. Generally older cows have less assisted than unassisted calvings.

The main difference was between cows and heifers so the differences in the levels of assistance within these groups were also compared ($X^2 = 77.67$, df = 3, $p < 0.001$). Significant differences were found in the assistance levels between cows and heifers (Figure 3.18).

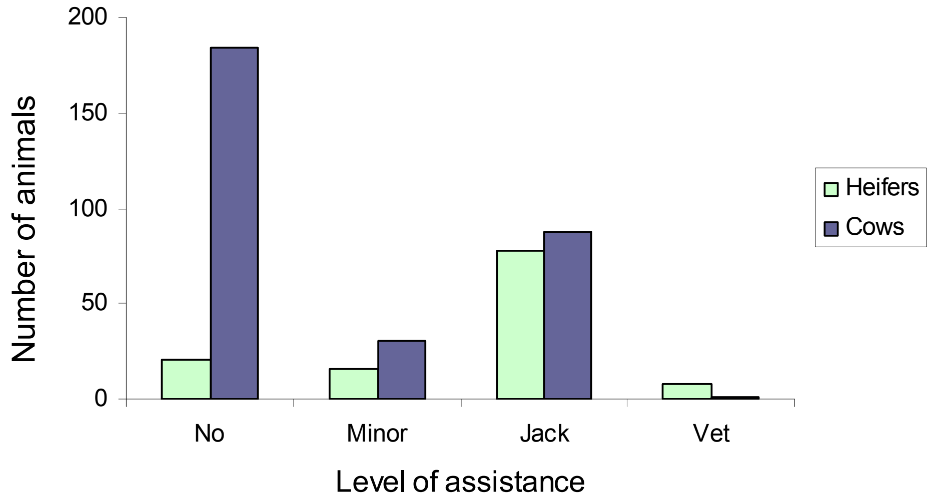

Figure 3.18
The degree of assistance compared between cows and heifers at Langhill Farm. Vet-assisted calvings include caesarean operations. Most heifers were assisted with a calving jack and most cows calved unassisted.

The number of times each stockman assisted with calving was compared to look for any differences between stockmen in the levels of assistance offered. Only the first twin of each pair was included because the second was usually attended by the same person and the highest assistance level was used for each pair of twins. Calvings assisted by a veterinarian were, by definition, all the same level of assistance, so these were excluded from the sample (n = 9). Calvings assisted by two people were also excluded because the number of people also indicated the increased need for assistance. WL did not attend many calvings so was excluded from the analysis.

There were significant differences between the assistance given by the three stockmen ($X^2 = 16.81$, df = 4, p = 0.002). SB was the closest to the average proportions of each level of assistance, FD used the jack fewer times than average, and JK used the jack more than the typical number of times (Figure 3.19).

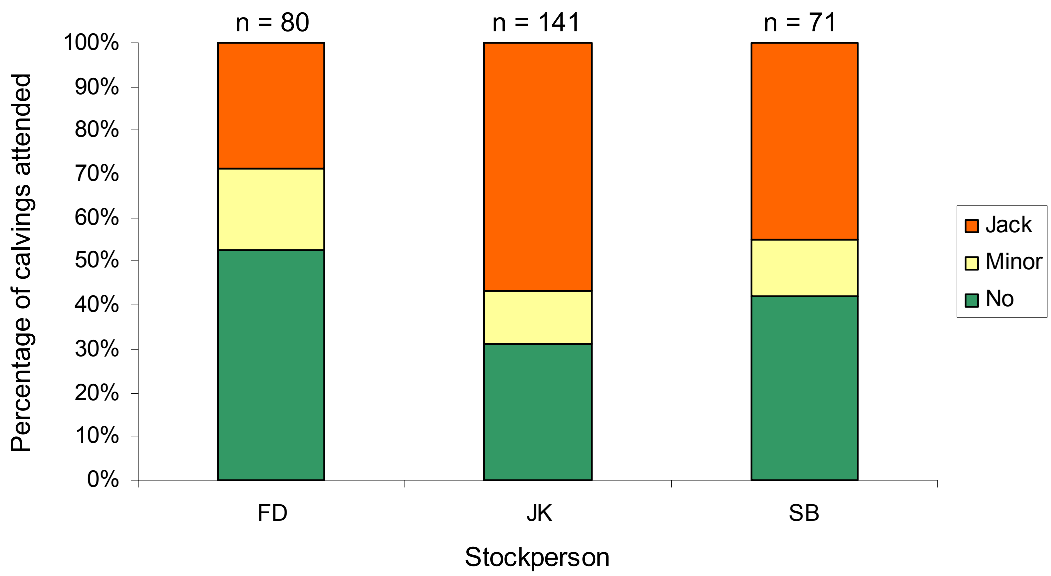

Figure 3.19
The levels of assistance provided by each of the three stockmen. SB represents the average proportions of no, minor or jack-assisted. JK used the calving jack more often than average and FD used it less that average.

Calvings from beef and dairy sires were compared for three levels of assistance; none, minor and jack or more serious. Each set of twins was only included once because the sire would be the same for each. There was no significant difference between calvings from beef and dairy sires in the need for assistance ($X^2 = 4.676$, df = 2, p = 0.089).

The assistance scores of twins and single calves were compared to see if there were more problems with twin calvings. Twins were included individually. Those attended by a veterinarian (including caesarean sections) were included with the jack-assisted group. Twin calves received minor assistance more often than single calves, and were less frequently assisted using a jack (X^2 = 13.050, df = 2, p = 0.001). When assistance was scored as assisted or not, twins still received significantly less assistance than single calves (X^2 = 6.651, df = 1, p = 0.01). The assistance of single and twin calves can be seen in Figure 3.20.

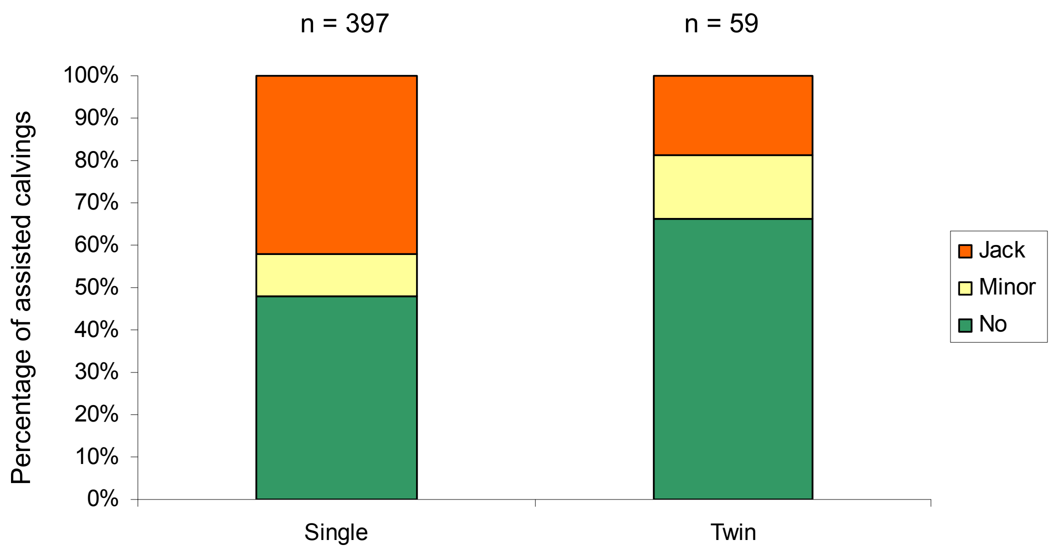

Figure 3.20
The percentages of single and twin calvings that were unassisted, given minor assistance, or assisted using a calving jack are shown. Dams with twins are more often given minor assistance and less often assisted with a jack than those with single calves.

For the cows that were in both years of the study, assistance scores were compared between years to see if those that were assisted one year were more likely to be given assistance again the following year ($X^2 = 14.376$, df = 4, $p = 0.005$). These were significantly different from the expected values compared to if there was no influence of the first year on the second (Figure 3.21).

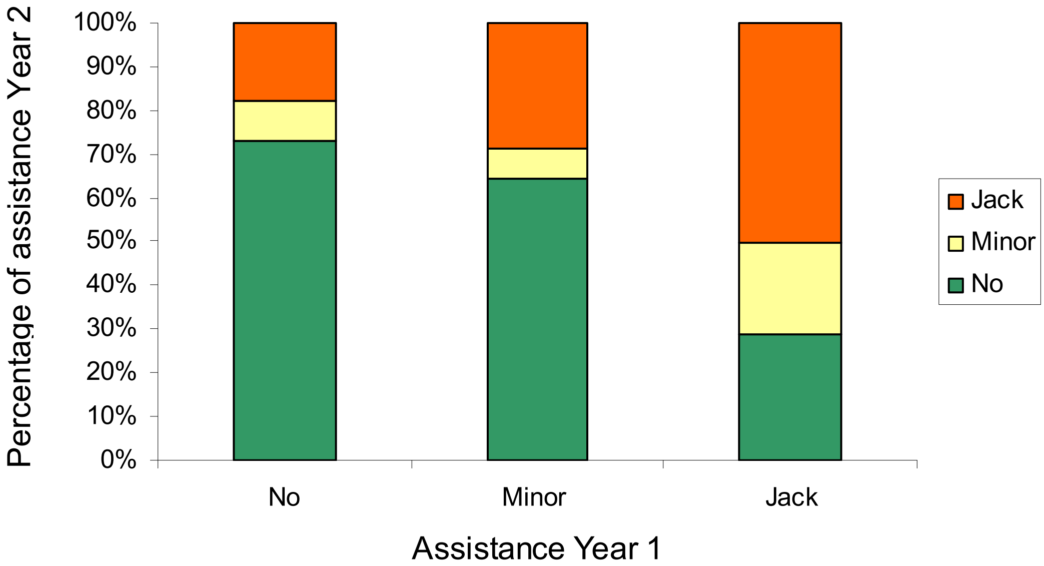

Figure 3.21
A comparison of assistance scores during Year 1 and Year 2 of the study showed that animals that were assisted with a jack (or vet, including caesarean sections) one year were more often assisted with a jack (or vet) again the following year.

This result was still significant when heifers were excluded from the analysis (X^2 = 10.02, df = 4, p = 0.045). When heifers were tested alone, with assistance simplified to assisted or not because of the smaller sample, there was no difference between the first and second years (X^2 = 0.823, df = 1, p = 0.364). Both of these variations are shown in Figure 3.22.

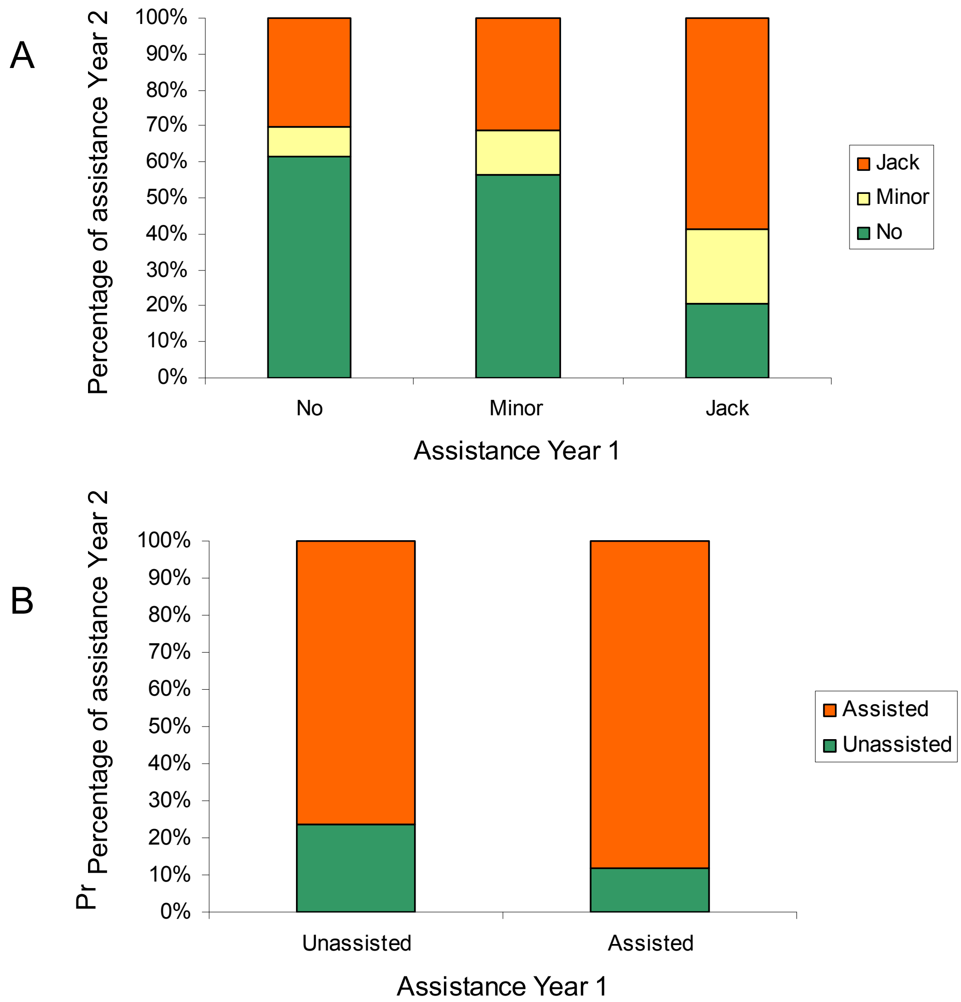

Figure 3.22
A. Comparison of assistance over two years in cows (parity 2+) only (n = 84). Cows assisted using a jack in the first year were more likely to be assisted with a jack again the next year.
B. Comparison of the assistance given to heifers over two years (n = 34). There was no significant difference in assistance in the second year (second calf) whether they were assisted as heifers or not.

Calf weights were only available for live calves in 2006-2007. Only single calves were included in the analysis because twins tend to weigh less. No significant differences were found between the weights of unassisted, minor, jack or vet-assisted calves ($F_{3,126} = 1.60$, $p = 0.192$).

Differences between single, live male and female calves in the level of assistance received (none, minor and jack or vet) were tested ($X^2 = 8.179$, df = 2, $p = 0.017$) and found to be statistically significant (Figure 3.23).

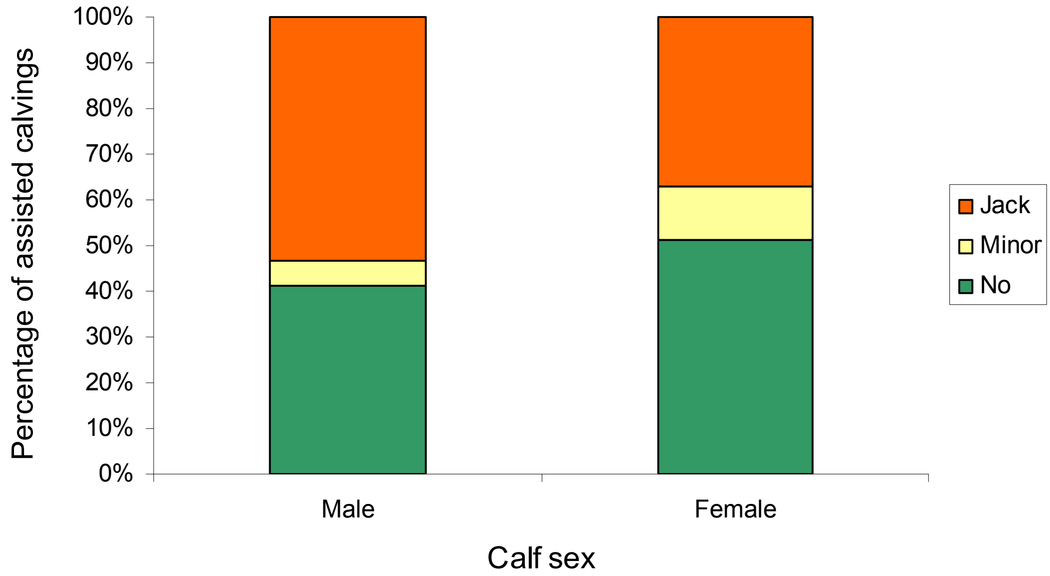

Figure 3.23
The levels of assistance given to single male and female calves. Male calves were assisted using a jack more often than females, which calved without assistance on more than 50% of occasions.

3.2.3.2 Risk factors associated with calf mortality

Of the 248 calves born in 2006-2007, 18 were dead or died at birth (7.3%) and 5 died (2.0%) within two days of birth. These numbers were slightly lower in 2007-2008 when 15 of the 232 calves were dead or died at birth (6.5%) and only one died within the first two days.

The mortality of calves in the different months of the calving season was summarised to see if there were any seasonal effects that might suggest a reason for the mortality rates. There did not appear to be a trend of change in mortality rate over the months of the calving season, or any similarities between the two years (Table 3.03).

Table 3.03 Calf mortality rates for each month of the calving season

Month	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
2006-07										
No. calvings	7	24	33	34	30	26	23	49	16	6
Mortality rate (%)	28.6	4.2	6.1	11.8	13.3	3.8	4.3	12.2	12.5	0
2007-08										
No. calvings	9	26	35	38	25	26	19	24	19	11
Mortality rate (%)	0	7.7	5.7	7.9	16.0	7.7	5.3	8.3	0	0

The survival of calves born from cows and heifers was compared and the mortality rate was found to be significantly higher in heifers ($X^2 = 20.010$, df = 1, $p < 0.001$). This difference is shown in Figure 3.24.

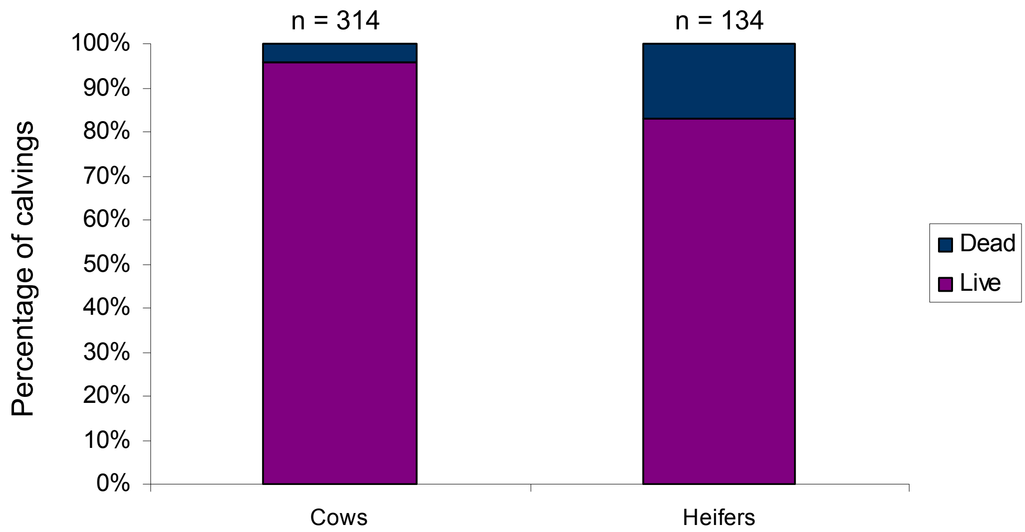

Figure 3.24
The mortality rates of calves born from cows and heifers. This was significantly higher for heifers (17.2%) than cows (4.5%). Pairs of twins were scored as dead if either or both of the calves were dead.

The mortality rates of calves from beef and dairy sires were not significantly different ($X^2 = 0.011$, df = 1, $p = 0.915$). The percentages of dead calves were 7.4% and 7.8% for dairy and beef, respectively.

The survival of twin calves was scored as live when both were live, or dead if either or both calves were dead. There was a significant difference in the number of single and twin calves which died at, or shortly after, birth ($X^2 = 12.747$, df = 1, $p < 0.001$). This difference is shown in Figure 3.25.

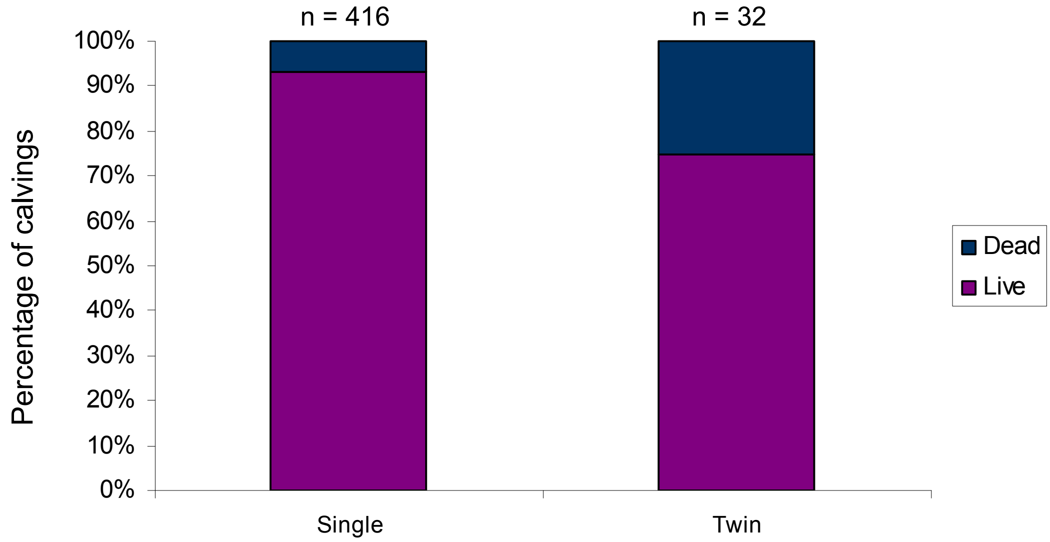

Figure 3.25
Calf mortality rates for twin and single calvings. This was higher for twin calves, with 8 pairs (25%) in which one or both died, compared with only 29 (7%) single calves that died.

The mortality of calves from dams that were in both years of the study were compared between the two years to see if having a stillborn calf one year increased the chance of this happening again the next year. The three dams that had dead calves the first year did not have dead calves again in the following season.

Assistance scores were available for 456 calves out of the 480 born in the study. These were simplified into no assistance, minor assistance, and assistance with jack (which also included veterinary intervention). The survival of each calf, classified as either live or died within two days, was tested to see if calves that required assistance at birth were less likely to survive (X^2 = 11.744, df = 2, p = 0.002). A significantly higher proportion of assisted calves died than those from unassisted calvings (Figure 3.26).

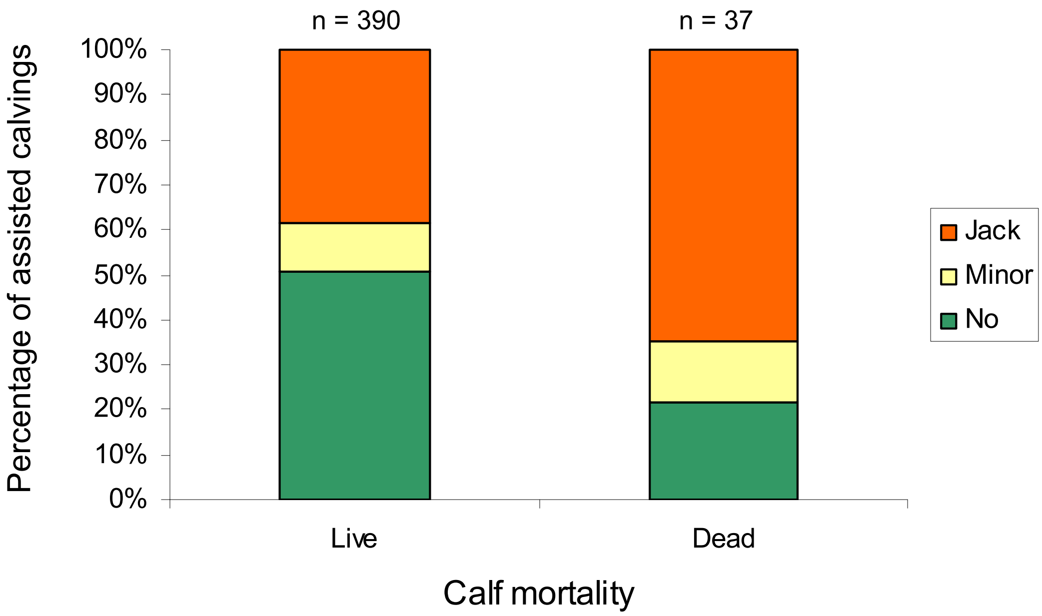

Figure 3.26
The levels of assistance given to calves that died and those that survived. A higher percentage of calves that died had assisted births using a calving jack or attended by a vet than those that survived.

There was no significant difference in the survival (live, stillborn or died within two days) of single male and female calves (X^2 = 0.299, df = 1, p = 0.584).

3.2.3.3 Variables associated with extended calving intervals

Calving intervals were calculated for the 125 cows that were in both years of the study. These ranged from 329-548 days, with a median of 385 days (Figure 3.27).

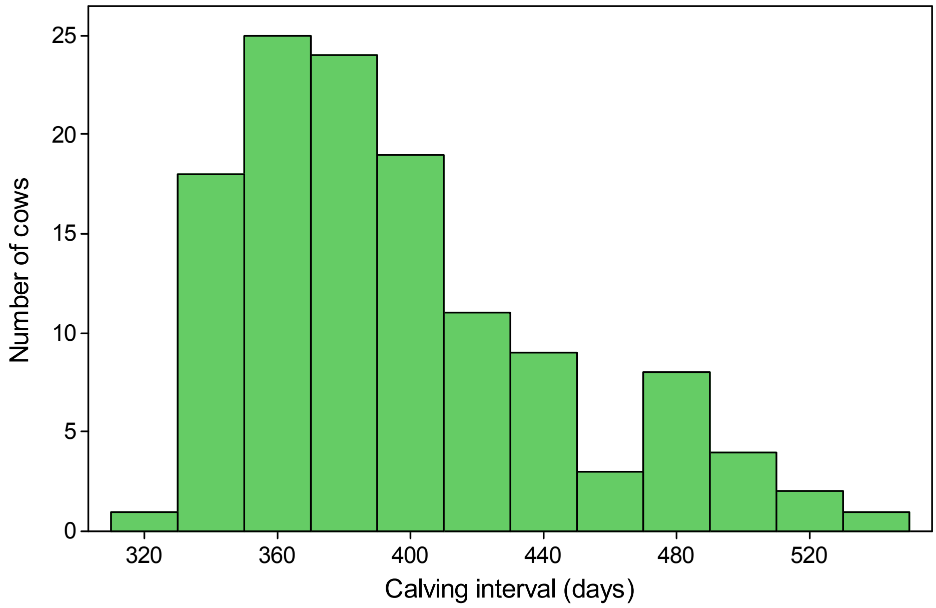

Figure 3.27
Histogram showing the distribution of calving intervals of 125 cows from Langhill Farm.

Calving intervals are partly a result of gestation length but there are more variables that have an influence, such as the time from calving until first service and conception rate. A significant but weak positive correlation (r = 0.279, p = 0.002) was found between calving intervals and gestation lengths (Figure 3.28).

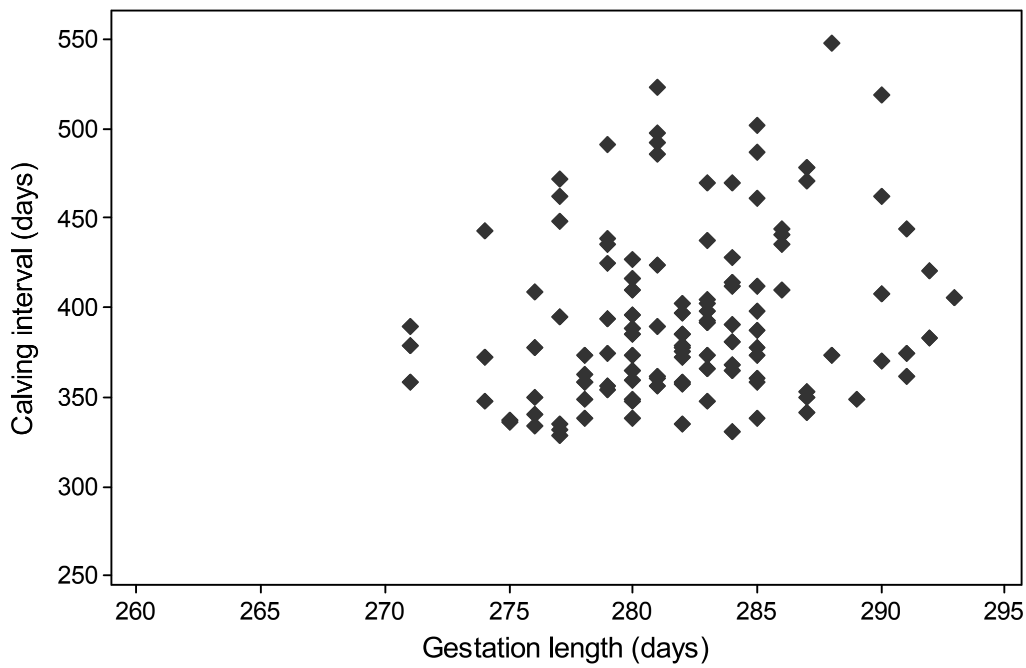

Figure 3.28
Scatter plot showing the correlation between gestation lengths and calving intervals.

Parities of five and higher were combined to make five parity groups (1, 2, 3, 4, 5+) with adequate sample sizes and significant differences in calving interval were found between parities (H = 10.75, df = 4, p = 0.03). Older cows had shorter calving intervals (Figure 3.29).

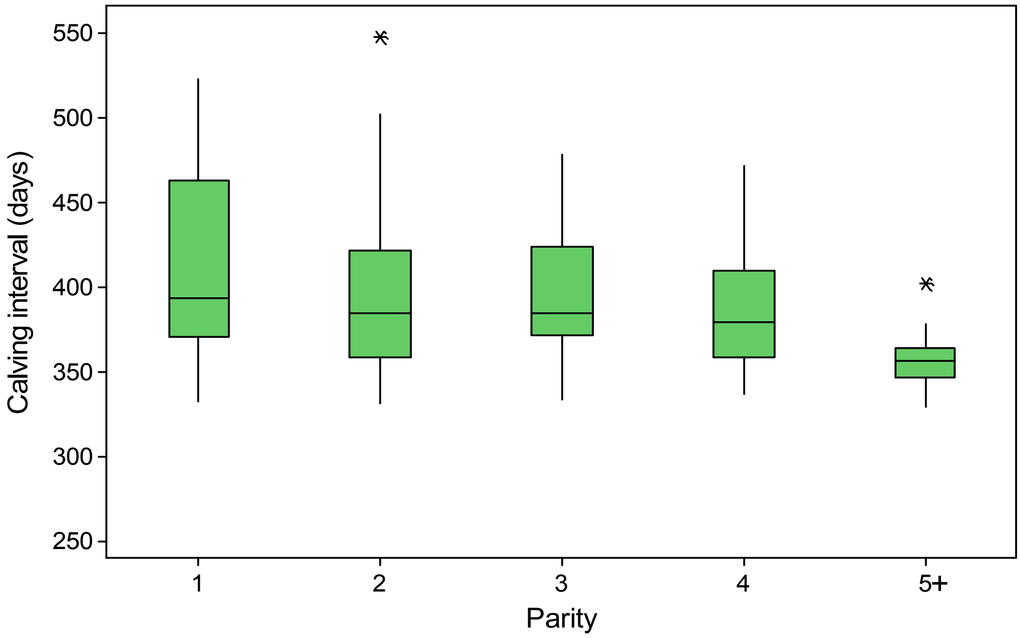

Figure 3.29
Box plots showing the calving intervals of different parities. Heifers (parity one) had a median calving interval of 393.5 days (n = 36). The shortest were seen in cows with parities of five and above, with a median of 356 days (n = 10).

Longer calving intervals were found in cows that had beef calves (U = 2253.5, $p < 0.001$). The median calving interval was 373 days for dairy calves (n = 92) and 436 days for beef calves (n = 33) (Figure 3.30).

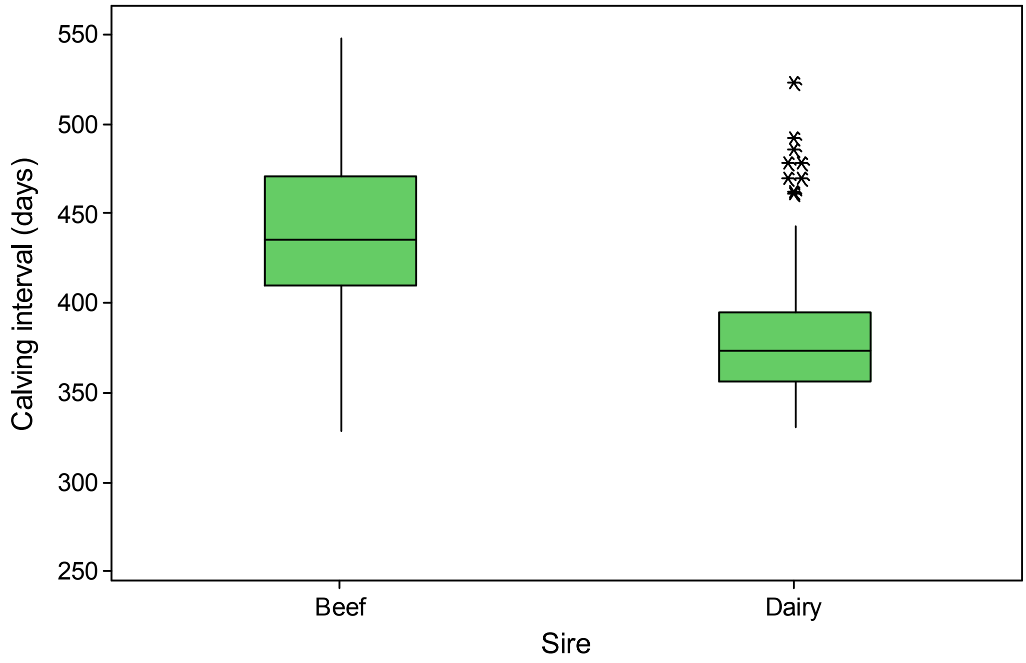

Figure 3.30
Box plots of the calving intervals of cows inseminated with beef or dairy semen. Longer calving intervals were observed in those that calved to beef sires.

There was no significant difference between the calving intervals following twin and single calvings (U = 470.5, p = 0.359). The median calving interval after twins was 374 days, ranging from 349.5-444 days (n = 9) and after single calves this was 385 days, with a range of 329-548 days (n = 116).

No difference was found between the calving intervals following calvings with dead or live calves as the ranges overlapped completely (U = 601.5, p = 0.745). There were fewer calvings with stillborn calves and these were followed by a median calving interval of 375 days (range 340-491 days, n = 9). The median calving interval was longer after live calves at 385 days, but the sample size and range were also much larger (range 329-548 days, n = 116).

There was no significant difference between calving intervals after calvings that were assisted and those that were unassisted (H = 6.19, df = 3, p = 0.103) or between cows that had milk fever and those that did not (U = 7528.5, p = 0.113).

3.2.3.4 Potential risk factors for milk fever

In 2006-2007 there were 16 cases of milk fever, which is 7.0% of the 229 individuals that calved. This was higher in 2007-2008 when there were 32 cases out of 219 animals, which is equal to 14.3%.

Seasonal effects on the prevalence of milk fever were examined by comparing the number of cases each month. The highest numbers of cases were seen in September, October, January and March (Table 3.04).

Table 3.04 Number of cases of milk fever shown by month (2006-2008)

Month	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Number of calvings	14	41	56	63	48	43	38	54	28	15
Cases of milk fever	1	7	7	5	3	6	3	12	3	1
Milk fever rate (%)	6.7	14.6	11.1	7.4	5.9	12.2	7.3	18.2	9.7	6.3

There was no significant difference between the average gestation lengths of cows which developed cases of milk fever and those with no milk fever (t = 0.67, df = 59, p = 0.505). Cows with milk fever had an average gestation length of 281.9 ± 4.9 days (n = 47) and those without had an average gestation of 282.4 ± 4.9 days (n = 335).

The difference in the incidence of milk fever between parities was statistically significant (X^2 = 87.670, df = 5, p < 0.001). First and second parity individuals had fewer cases of milk fever than would be expected, third parity cows had roughly the expected number of cases, and parities of four and above had the most cases of milk fever (Figure 3.31).

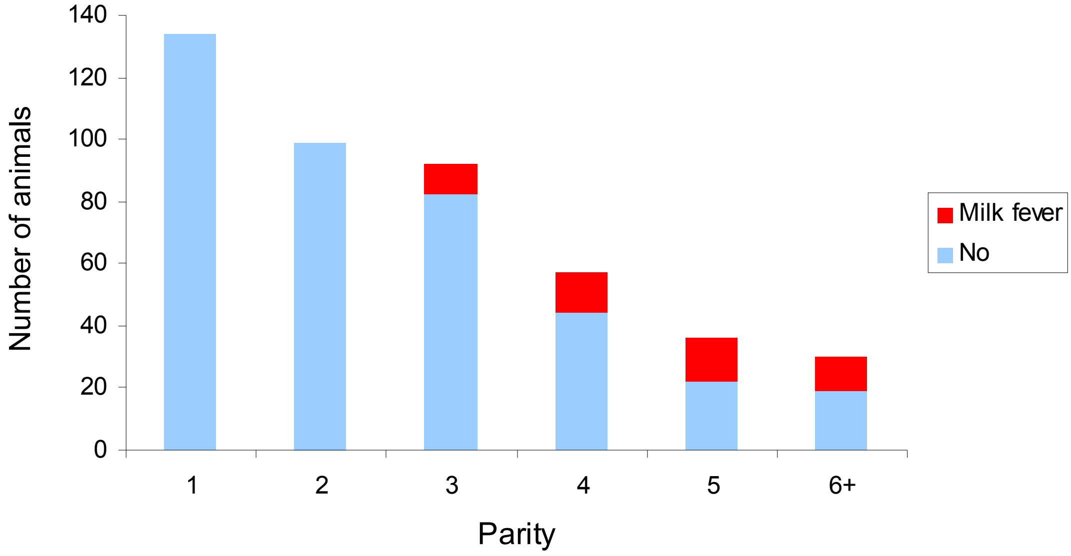

Figure 3.31
The number of cases of milk fever in cows of different parities. There were no cases in cows of parities one and two, and the incidence increased with age.

There was no significant difference between the number of cases of milk fever between cows mated to beef and dairy sires (X^2 = 1.026, df = 1, p = 0.301). No significant difference in the incidence of milk fever following single and twin calvings was found (X^2 = 0.869, df = 1, p = 0.377) and milk fever was not associated with an increase in calf mortality (X^2 = 1.188, df = 1, p = 0.236).

Cows with milk fever were significantly less likely to have been assisted at calving (X^2 = 8.902, df = 2, p = 0.012). The results showed that cows with milk fever were assisted with a calving jack or by a vet less often than healthy cows (Figure 3.32).

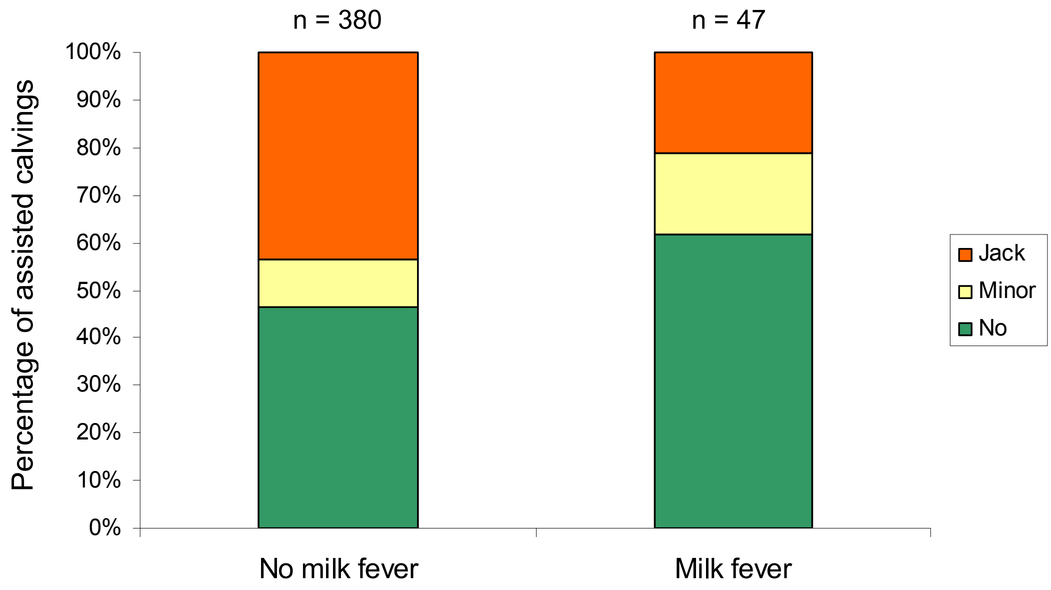

Figure 3.32
The levels of assistance given to animals that had milk fever and those that did not. Less cows with milk fever were assisted than those that did not have milk fever during the transition period, mainly due to the lower proportion of jack or vet assisted calvings.

Individuals that were in both years of the study were used to compare the recurrence of milk fever between years and see if cows that have previously suffered from milk fever are more likely to suffer from future cases. Only eight of the 16 cows that had milk fever in the first year of the study remained in the herd for the second year. Six of these eight cows had milk fever again at their next calving (75%), suggesting that there is a high risk of cows that have had milk fever previously to have recurring cases.

Single calves from cows with milk fever weighed 48.2 ± 4.2 kg (n = 6) on average and those from healthy cows weighed an average of 46.9 ± 5.0 kg (n = 124) but this difference was not significant (t = -0.69, df = 5, p = 0.521).

3.2.4 Discussion

3.2.4.1 Variables associated with assisted calvings

The levels of assistance given to cows were fairly consistent between the two years but assistance rates appeared to be relatively high, at 47.1% overall. However, this is the rate of assistance from very minor to surgical intervention, so includes a lot more cases than reported in many other studies. The costs of calving difficulties were calculated by McGuirk *et al.* (2007) as £106 for a calving requiring slight assistance and £364 for a serious problem at calving. Using these figures to estimate the annual costs of calving problems at Langhill farm gives totals of £15,102 and £11,434 in 2006-2007 and 2007-2008, respectively.

Assistance rates vary widely between farms. Whitaker *et al.* (2000) looked at assistance rates in 340 UK dairy herds and found that this ranged from 0-57% between farms, with an average of 8.7%. Assisted calvings were defined as those requiring veterinary assistance or traction applied by farm staff for longer than a few minutes, so included fewer cases than the definition used in the current study.

No seasonal variation or difference in gestation length was found between the levels of assistance required by cows at calving over the course of this study. This is concurrent with the results of Dohoo *et al.* (1984), who also found no seasonal pattern in dystocia. However in a study of cows in the United States, cows calving in the winter were 15% more likely to suffer from dystocia than those which calved in the summer (Johanson and Berger, 2003).

More calvings were assisted during the day, and more cows calved without any assistance at night. This may be due to there being less assistance available during the night, with the presence of stockmen and opportunities for assistance being reduced at this time. A similar trend was observed in a study of beef cows. In this case the highest incidence of abnormal calvings (22.2%) was seen between 11:00-

15:00, and the lowest incidence (12.1%) was between 23:00-03:00 (Yarney *et al.*, 1982) suggesting that there may be a real biological influence.

Heifers were more often assisted at calving than older cows. There is strong agreement between studies that this is a genuine concern. One study which compared serious calving difficulties in Swiss cows, found a high frequency of problems in heifers (Bleul, 2008). Lombard *et al.* (2007) found that 51.2% of calves from heifers required assistance, compared with only 29.4% of calves from multiparous dams. These rates are fairly high because those requiring slight assistance were included in the figures too. However, it is likely that many did not require assistance and these high figures may result from the attitudes of the stockmen rather than genuine problems. Higher assistance levels are also seen in beef heifers (Nix *et al.*, 1998). In addition to this difference between heifers and older cows, there is some evidence that a quadratic relationship exists with age, where both young cows (heifers) and those of age 10+ require the most assistance (Dohoo *et al.*, 1984). The sample size of older cows was not large enough to look for this type of relationship in this study.

There were differences between the number of assisted calvings each stockman was involved with. JK used the jack more frequently than the others, and FD used the jack the least often. It may have been that JK happened to attend to more difficult calvings in comparison to the others, or this could be a sign of differences in the attitudes and decisions made by each stockperson. There have been a few studies of differences in stockpersons' attitudes towards cows and how this affects their behaviour when caring for them (Hemsworth *et al.*, 2002; Waiblinger *et al.*, 2002). These studies have mainly focussed on the variation between the attitudes of people who handle cattle and what effect it has on the behaviour and production of the cows. Another study of the attitudes of veterinarians asked them to assign a pain score to various conditions and surgical procedures in cattle. The results showed that there is a lot of variation in how people perceive pain in cows. Dystocia received a median pain score of seven but the range of scores went from two to ten, showing that the opinions were extremely variable within the veterinary profession (Huxley and Whay, 2006).

There was no significant difference in the level of assistance required by calves from beef and dairy sires, although there was some evidence that supported the expected result that beef calves would require more assistance than those from dairy sires.

Twin calves were more commonly given minor assistance than single calves, and fewer twin births were assisted overall. In beef cattle, twin calves require assistance more frequently than single calves and dystocia was not affected by parity in twin births in the same way as for single births (Echternkamp and Gregory, 1999).

Dams which needed assistance one year were more likely to be assisted again during the following year. This suggests that there may be some cows which have a predisposition to dystocia and are more likely to have recurring problems at calving, possibly due to anatomical differences. This was not the case in the study by Calavas *et al.* (1996) who found no recurrence of calving difficulty between two lactations in French dairy cows.

There was no difference between the weights of calves which were assisted at birth and those which were not. As the sample did not include the calves which died within 24 hours of birth, it is possible that an important part of the sample was missed. In a study done in the United States, the dystocia rate was strongly linked to the birth weight of the calf and the risk of calving difficulty increased 13% for each kg of birth weight (Johanson and Berger, 2003). Similar results were found by other studies of dairy (Colburn *et al.*, 1997) and beef calves (Smith *et al.*, 1976; Nix *et al.*, 1998). There is also one study which suggests that beef calves which are lighter than average may require more assistance, in addition to the heavier calves (Berger *et al.*, 1992).

In this study, male calves needed assistance more frequently than females. Male calves were assisted using a calving jack (or more serious methods) in 53.2% of calvings and females only required this level of assistance in 37.1% of cases. These percentages are comparable to those reported by Lombard *et al.* (2007), with 40% of bull calves and 33% of female calves requiring assistance. Other studies have also found that serious calving difficulties are more frequent in male calves (Bleul, 2008) and one measured the increased risk of dystocia in male calves as 25% (Johanson and Berger, 2003).

3.2.4.2 Risk factors associated with calf mortality

Calf mortality was higher during the first year of the study, and the overall rate between the two years was 8.1%. This is very close to the 8.2% overall proportion of stillbirths found by Lombard *et al.* (2007). In another study the mortality rate within the first 24 hours of life was 7.1% (Johanson and Berger, 2003) but in a study of Irish dairy herds, the overall perinatal mortality rate was much lower than this, at 4.3% (Mee *et al.* 2008). Mee *et al.* (2008) also collated results from a number of different studies and found overall mortality rates ranging from 2.0% to 9.6%.

Seasonal differences in calf mortality were not tested statistically but peaks were observed in the months of November, December and March, with the highest mortality rate in December. This shows some agreement with the results of a study which reported higher mortality rates in the winter (October to March) compared to the summer (April to September), although it is not made clear if these cows were housed indoors or kept outdoors at calving (Johanson and Berger, 2003). The months with the highest mortality also seemed to be the months during which there were the most cows calving. The correlation between mortality rate and number of calvings was tested but there was no strong evidence. However, it is possible that there is an increased risk of mortality when there are more cows in the calving shed. Variables that could contribute to this would be a lack of space, increased social stress from changing members of the group and increased competition for positions at the feed face. This would be an interesting trend to investigate further.

Calves born from heifer dams (17.2%) suffered from much higher mortality rates than those from older dams (4.5%). This is approximately four times higher in heifers, which is a larger difference than seen in any other study. Calf mortality data collated from a number of studies of dairy calves showed rates of 3.0-12.1% for heifers and 2.0-9.6% when both heifers and cows were included (Mee *et al.*, 2008). The increased chance of calf mortality in heifers was measured as 2.4 times by Johanson and Berger (2003) which would fit with the ranges reported by Mee *et al.* (2008). The same trend is apparent in beef cows, with lower calf mortality seen in multiparous cows (Berger *et al.*, 1992; Nix *et al.*, 1998). The mortality rates in beef cows were within the same ranges as those found in dairy cows, with 4% mortality in multiparous dams and 7% in heifers (Nix *et al.*, 1998).

Twin calves suffered from higher mortality rates than singles. Lombard *et al.* (2007) found the same result and this is confirmed by Mee *et al.* (2008), who also showed that this relationship varies significantly with age. In younger dams, the risk of mortality was higher in twin calves than in older dams. However, in all cases the mortality was much higher in twins than for single calves.

There was no indication that calf mortality was connected between years in the same dam. However, the sample size was very small with only three cows with dead calves in the first year calving again during the second year of the study. In a larger study of Irish dairy herds, it was found that cows which had previous calf mortality had four times the chance of calf mortality again the next year (Mee *et al.*, 2008).

There was a strong link between calf mortality and increased levels of assistance, with dead calves being more likely to be given assistance with a calving jack, or by a veterinarian. This association is repeatedly reported in a number of different studies of dairy (Johanson and Berger, 2003; Tenhagen *et al.*, 2007; Lombard *et al.*, 2007) and beef cows (Nix *et al.*, 1998). It is difficult to establish if a stillborn calf is the reason that assistance is needed, or if the need for assistance results in the death of the calf. A post-mortem study conducted in Sweden attempted to establish this and found that around half of the 67 dead calves died as a result of a difficult calving. The cause of death could not be determined for a number of the calves, but dystocia appeared to be the more likely reason for stillbirths than vice versa (Berglund *et al.*, 2003).

No difference was found between the mortality rate in male and female calves. In a large study of dairy herds in Ireland, a slightly higher risk of calf mortality was observed in male calves. This was partially explained by the increased rate of assistance required for male calves (Mee *et al.*, 2008). However, in beef calves the same situation was also observed, with lower mortality rates in female calves (Berger *et al.*, 1992; Nix *et al.*, 1998).

3.2.4.3 Variables associated with extended calving intervals

Calving intervals were not normally distributed and were positively skewed because there is a minimum possible calving interval after which a cow can conceive and produce a healthy calf. Cows normally display their first signs of oestrus from 40 days after calving and will be inseminated between 60-80 days postpartum (Phillips, 2001). The minimum gestation length is normally considered as 240 days, with any shorter duration generally classed as an abortion (Hansen *et al.*, 2004b). Therefore, there are biological limitations regarding how short the calving interval can be but the maximum interval is decided by the management of the herd.

There were a few variables which were associated with differences in calving intervals. A positive correlation was found between gestation lengths and calving intervals, as would be expected, but there was not a strong association between them suggesting that there are many other variables involved which may have a greater influence.

Older cows were shown to have shorter calving intervals, with the largest difference seen from the fifth lactation onwards. It is difficult to determine if this is a real biological effect or a result of management choices because this may result from selection as cows with reproductive problems are removed from the herd. This would leave only the most fertile and productive individuals, with short calving intervals, beyond their fifth lactation (Thomsen and Houe, 2006).

One difference in calving intervals which is definitely influenced by the management of the cows is that longer calving intervals preceded the birth of beef calves, than dairy calves. This is most likely to result from the less fertile cows which take longer to conceive are often artificially inseminated using beef semen (such as Fertility Plus) to increase their chances of conception. The average gestation length of beef-cross calves is also longer than that of pure-bred dairy calves, by an average of four days, so this will also contribute to this observed difference. The decision to breed these cows using beef semen will also be influenced by the higher value of beef-cross calves towards the end of the calving season, when enough dairy replacement heifers have been born to sustain the herd size.

The biological influences studied do not appear to show many differences in calving intervals in this study, although results have been found in other studies. There was no difference between the calving intervals following the birth of twin and single calves. However, in beef cattle twin calvings are followed by longer average calving intervals and lower conception rates (Echternkamp and Gregory, 1999). The average calving intervals did not appear to be affected by preceding calf mortality, or the level of assistance given at the previous calving, although there was a tendency towards longer intervals after more difficult calvings that was not significant. Another study found a difference of 33 days open following extreme calving difficulty compared with cows that had no problems (Dematawewa and Berger, 1997). Another measure of reproductive success following calving difficulty is to calculate the proportion of cows that have conceived by 200 days in milk. This was shown to be significantly less for cows which had experienced calving difficulty in comparison with normal controls (Tenhagen *et al.*, 2007). Beef heifers also had longer calving intervals after calvings with higher difficulty scores, but their conception rates were unaffected (Colburn *et al.*, 1997). These combined effects on future reproductive performance, and also a decrease in milk production of cows with calving difficulties, mean that problems at calving have a fairly large economic cost for the farmer. This has been estimated as £110 for a slight problem at calving and £350-400 in cases with serious calving difficulties (McGuirk *et al.*, 2007).

Those cows which had milk fever in the first year of the study did not have significantly longer calving intervals than those which did not. The sample size for cows with milk fever was very small which may have hidden any difference that was present, so this result is not conclusive. With a larger sample of individuals, cows that have had milk fever are generally inseminated later and conceive later than healthy cows (Vacek *et al.*, 2007).

3.2.4.4 Potential risk factors for milk fever

There were more cases of milk fever in 2006-2007, than in 2007-2008. The average incidence of milk fever in dairy cows is 4-10% (Phillips, 2001; Whitaker *et al.*, 2004), which covers the 7.0% incidence observed in 2006-2007 but is lower than the 14.3% incidence observed during the second year. No reason for this large increase in the second year of the study was identified as there were no major changes in the management of the herd at this time.

Large differences in the number of cases of milk fever were found between parities. None of the cows suffered from milk fever during their first or second lactations, and the incidence of milk fever increased with age. In a study of multiple herds, a small percentage of first (0.03%) and second (0.5%) lactation cows had milk fever, but this was much lower than the levels observed in later lactations (van Dorp *et al.*, 1999). The reason why older cows are most susceptible is because older cows have a lower concentration of calcium in their blood at calving, resulting from a reduced ability to mobilise calcium because of changes in their vitamin D receptors and bone physiology (Phillips, 2001).

No seasonal pattern in the incidence of milk fever was observed between months but there were peaks in the number of cases in September, October, January and March. Other studies also found no significant effect of season (Dohoo *et al.*, 1984; van Dorp *et al.*, 1999). No differences in the incidence of milk fever were observed between cows which were mated to beef or dairy sires, those which had twin or single calves, or those which had live or stillborn calves. Cows with milk fever were assisted less often with a calving jack than those which did not develop milk fever. Calavas *et al.* (1996) did not find any association between milk fever and calving difficulty either, but a difference was expected. Milk fever is often associated with increased risk of calving difficulty because low levels of calcium reduce the strength of uterine contractions, making calving more difficult and also increasing the risk of calf mortality (Mulligan *et al.*, 2006).

The majority of cows (75%) that had cases of milk fever during the first year of the study had recurring cases the second year. The sample size was very small in this instance but the recurrence of milk fever was also seen in larger studies and is believed to be caused by a combination of individual predisposition and the after-effects of previous cases (Dohoo and Martin, 1984; Calavas *et al.*, 1996).

3.3 Summary of findings

3.3.1 Part 1: Calving prediction

Many variables were identified that were associated with variation in gestation lengths. These were the season, parity, breed of sire and if the dam was carrying a single or twin calves. The largest difference was seen between single and twin calves, so if twins could be identified during pregnancy, this information could help to predict the date of calving. However, there are no variables that can helpfully predict if calvings are more likely to happen during the night or during the day. The stockmen used signs of calving that were also reported in the literature but different signs were not observed between cows and heifers or between assisted and unassisted cows. Most of these observations were made within four hours before calving and assisted calvings were generally noticed earlier.

3.3.2 Part 2: Some risk factors for problems during the transition period

Calving difficulty and calf mortality were closely linked, with more assisted than unassisted calves dying within the first 24 hours after birth. The most important difference for management purposes was seen between heifers and multiparous cows. Heifers required assistance more often and also had a higher calf mortality rate, so need to be monitored carefully at calving. Twin calves also carried a higher risk of calf mortality, and male calves are assisted more often than females, but these are more difficult to avoid or control. The only differences in calving intervals were found between dams of different ages, with shorter calving intervals in older cows. Problems at previous calvings have the potential to lead to extended calving intervals but these differences were not observed. Milk fever is not a problem in heifers but can be common during later lactations and cases can be recurring. As with other health problems, it is important to monitor those with a history of previous conditions to identify recurring cases.

Chapter 4: The behaviour of dairy cows before, during and after parturition

4.1 Introduction

In order to predict the onset of calving in dairy cows, consistent behavioural changes before calving must first be identified. Changes in the frequencies and durations of normal behaviours and abnormal postures are often observed before calving and form part of the basis of the current methods of prediction used by farm staff. Changes in behaviour are also widely reported in the research literature which suggests that they have the potential to provide important information on the progress of parturition.

For a specific behaviour to be used to predict the time of parturition it must show a measurable change that is consistently seen between individual cows. However, if there is no single measure of behaviour that can provide this type of prediction by itself, it is possible that a combination of behaviours could be measured to improve the accuracy and ability to generalise between individuals. It is also important to establish if these behaviours occur early enough before calving for them to be useful for any practical application.

4.1.1 Duration of normal parturition in dairy cows

The duration of parturition is variable between individuals, with extended births associated with large calves, twins and abnormal presentations. Parturition is also longer if it is the first calving, if cows are frequently disturbed, or are debilitated by ill health or under-nutrition (Hafez and Hafez, 2000). The first stage, from cervical dilation until the water bag bursts, can last from just over two hours to between six to 24 hours and tends to be shorter for older cows (Ball and Peters, 2004). The second stage, when the calf is delivered through the pelvic canal, is usually completed in about an hour (Phillips, 2002) but can range from 30 minutes up to four hours (Ball and Peters, 2004). This stage of parturition tends to be longer in heifers than in multiparous cows, with respective average durations of 54.1 minutes and 22.5 minutes recorded in a study of beef cattle (Doornbos *et al.*, 1984). The third stage, from the birth of the calf until the placenta is expelled, normally takes from two to six hours (von Keyserlingk and Weary, 2007).

Cows are normally recumbent at the time of delivery and stand up very shortly after their calf is born to lick the birth fluids from her calf (Houwing *et al.*, 1990). Licking can continue for up to 1.5 hours and the birth membranes are usually ingested during the cleaning process. This time is very important for the development of a bond between the dam and her calf. Maternal behaviour is under hormonal control for the first few hours but after this time contact with the newborn stimulates the mother to remain maternal. Calves usually remain passive for the first 30 minutes after birth and will then begin to attempt to stand. Teat seeking activity is most intense when the calf first stands. There is a very strong drive for the calf to look for the udder and they will try and suckle almost any part of the cow's body (von Keyserlingk and Weary, 2007).

4.1.2 Expected changes in behaviour before and during parturition

Based on the existing literature, there are a number of behaviours that change prior to calving. Maintenance behaviours such as eating, ruminating and grooming decrease over a number of days before (Huzzey *et al.*, 2007). Then in the hours approaching calving there is an increase in lying duration and restlessness (Huzzey *et al.*, 2005). Restlessness can be characterised by an increase in the number of transitions between standing and lying, and an increase in the time spent walking. Tail raising and licking the ground are also expected to become more frequent during the final day as these behaviours are observed during the first stage of parturition during the majority of calvings (Wehrend *et al.*, 2006). The time from the appearance of the first signs of calving until parturition starts can range from 45 minutes to 14 hours (Lidfors *et al.*, 1994).

The tendency in the research work to date is for detailed studies to be conducted on a specific behaviour or group of behaviours. Longer trials have been conducted with the use of automatic recording systems but the behaviours that can be measured this way are limited to eating, drinking, standing and lying (Huzzey *et al.*, 2005; Huzzey *et al.*, 2007). In the case where all calving-specific behaviours were recorded, only their presence or absence was noted and observations were only made during the first stage of parturition (Wehrend *et al.*, 2006). Detailed behavioural observations of dairy cows during the 24 hours before calving have not been previously recorded. This could be used to identify behaviours that are indicative of parturition, show the most consistent changes and provide an indication of when these changes occur.

4.1.3 Research aims

The central aim of this chapter was to identify changes in behaviour that occur during the 24 hours before normal calving and may be useful for predicting parturition.

Four aims, focussing on different aspects of calving behaviour, were specified to guide the analysis;

1. To determine the time frame during which the stages of parturition and main events following birth are completed during normal calving in dairy cows.

2. To identify which behaviours show changes in daily averages prior to calving that are not observed during control observations.

3. To compare behaviour during six-hour periods before calving to determine the period during which changes become significantly different between calving and control observations.

4. To plot segmented regression lines against one-hour periods of behaviour before calving, to explore the approximate time before calving when each behaviour changes.

4.2 Methods

4.2.1 Selection of focal individuals

Multiparous cows were used to study normal calving behaviour, with the assumption that primiparous animals may behave differently. Cows requiring more than minor assistance at calving were excluded because their behaviour might also differ from those with normal, straightforward calvings. Differences associated with parity and assistance will be discussed in Chapter 5.

Cows with milk fever or other clinical problems were excluded from the dataset, along with cows that experienced any major disturbances during the calving period. Cows that calved on dates when there were problems with the video recordings were not used and preference was given to focal cows that could be seen clearly on the videos. Priority was given to cows for which there was corresponding accelerometer data for the work described in Chapter 6.

4.2.2 Collection of behavioural data

The methods used to record and analyse behaviour from video recordings were described in detail in Chapter 2. Specifically recorded landmark calving events were used to calculate the durations of the second and third stages of parturition. These were the times when the water bag burst (start of stage two), the calf was expelled (end of stage two and start of third stage) and the placenta was expelled (end of third stage). The time when the first stage started could not be accurately recorded so its duration was not calculated. The times when each cow stood and licked her calf after delivery were recorded, as were the latencies of the calf standing and suckling. These events following calving were only observed within six hours after birth because if calves are going to suck without help they are likely to do so by this time (Wesselink *et al.*, 1999).

Each cow was observed for the 24 hours up to the time when the calf was fully expelled to capture the behaviour before and during calving. This was known as the calving observation. A pre-calving, control observation was also made of each cow, 1-10 days (median = 3) earlier than the calving observation to allow comparisons to be made. Control observations were made three days before calving when there was accelerometer data available for that period of time or on the closest day there was accelerometer data for. As the cows did not all calve at the same time of day, the times of the control observations were matched to the calving observations for each individual to minimise any effect of circadian patterns of behaviour. Posture was recorded as a set of mutually exclusive states (standing, walking, lying), as was general behaviour (eating, drinking, ground licking, grooming, other). In addition to these states, specific events were scored during observations (tail raise, tail swish). The full ethogram with definitions for each of the behaviours is given in Chapter 2.

4.2.3 Statistical analyses

To determine the time frame during which the stages of parturition were completed, the median durations of the second and third stages were calculated, along with the minimum and maximum observed out of the 20 cows studied. Summary data were also collected for the latency of events after calving.

To identify which behaviours show changes prior to calving that are not observed during control observations, the total frequencies and durations of behaviours were compared between the 24-hour calving and control observations. These observations were repeated measures on the same cows so paired t-tests were used to analyse normally distributed data and one-sample Wilcoxon tests used to compare within-cow differences for data that were not normally distributed. Observations with any missing data were not excluded from this analysis.

To narrow down the time of changes before calving within the 24 hours before, the frequencies of lying, walking and tail raises, and durations of lying, walking, eating and ground-licking were calculated for each of the four six-hour periods within the observations. Of the resulting 160 periods, 27 periods with missing data were excluded from the analysis. Friedman's tests with multiple comparisons were used to examine any variation between the four control periods for each of the behaviours, and the same was done with the four calving periods. Where differences were observed, an appropriate non-parametric post-hoc test was used to identify which periods were significantly different (Zar, 1999). The relative changes before calving were investigated by calculating the within-individual differences between the calving and control observations for each behavioural variable. Variation between these differences during the four periods were tested using Friedman's tests in the same way that variation within control and calving observations were tested separately. All means are reported with their standard deviation and medians with their inter-quartile range (IQR), unless stated otherwise.

To explore the approximate time of changes before calving, a segmented regression was calculated for the calving data of each behavioural variable, using R (R Development Core Team, 2006). This analysis estimates the breakpoint between two fitted regression lines, assuming an abrupt change in the data. The analysis finds the point where the slope changes and the maximum variance is explained by the two regression lines. Each variable was summarised into one-hour periods with incomplete hours excluded from the dataset. This regression analysis does not account for repeated measures recorded from the same individuals and would normally be applied to continuous data but the large number of periods (24 one-hour periods) meant that it was possible to calculate preliminary results. Frequencies were tested with Poisson errors, as count data follow this distribution, and durations were expressed as binomial variables because at each time point during the observation the focal cow could either be lying or not lying. Breakpoints were considered to be potentially useful if they explained more than 40% of the variance in the calving data. When this was the case, the data were split at the nearest hour to the estimated break and separate regressions calculated for the two parts before and after the break. To check that any changes found were specifically associated with calving, the same analysis was done to look for breakpoints in the control observations.

4.3 Results

4.3.1 Summary of data collected

The experimental design required 960 hours of video analysis (20 cows, for two 24-hour observations each). Twelve hours were missing due to gaps in the video record and 31 hours were lost when cows were moved outside the area covered by cameras. The gaps in the behavioural observations for each individual are summarised in Appendix A. Missing data were not accounted for in the analysis of daily totals but periods with missing data were excluded from the rest of the statistical analyses. Some details of the cows observed for this part of the study and details of their calvings are given in Table 4.01.

Table 4.01 Summary information about the observed dams and their calvings
(* denotes missing values)

Cow ID	Parity	Calf sex	Calf weight (kg)	Sire
4	5	Female	50	Beef
13	2	Female	45	Dairy
30	2	Female	51	Beef
47	3	Male	46	Dairy
51	3	*	*	Dairy
53	3	Male	*	Dairy
80	2	Male	46	Dairy
85	9	Female	44	Dairy
101	3	Male	*	Dairy
122	2	Female	44	Dairy
130	3	*	43	Dairy
136	3	Female	51	*
156	3	Female	46	Dairy
187	4	Female	*	Dairy
189	2	Female	*	Dairy
191	2	Female	49	Dairy
205	2	Male	58	Beef
207	3	Male	57	Beef
216	2	Female	48	*
248	2	Male	*	Beef
Mean	3		48.4	
Range	2 - 9		43 – 58	

The behavioural observations provided concurrent recordings of a number of behavioural states and events (Figure 4.01). This was used to calculate frequencies and durations of specific behaviours during various intervals of time, for statistical analysis.

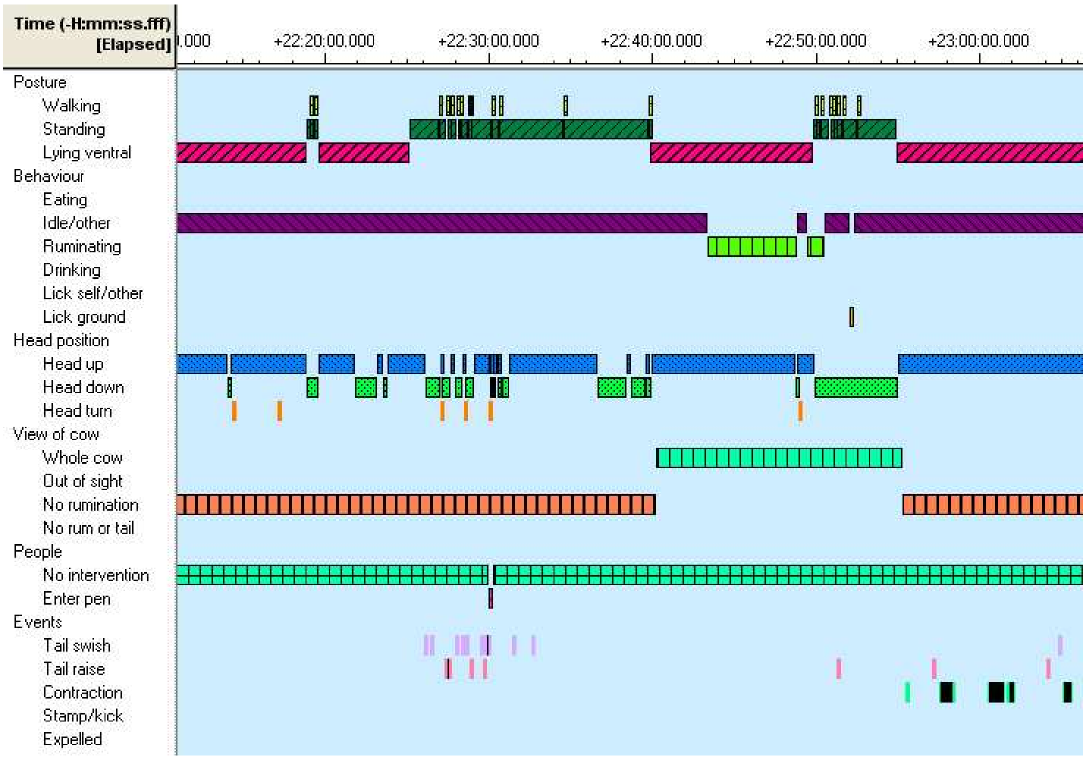

Figure 4.01
Visualisation of the behaviour of cow 248, from one to two hours before calving, from the Observer software. This shows how each category of behaviour is divided into mutually-exclusive states and how these are recorded concurrently.

4.3.2 Duration of normal calving and latency of events after calving

The duration of the second stage of parturition, from the water bag bursting until the calf was expelled, was recorded for 17 of the 20 cows observed. The median duration of this stage was 1.0 hours, and ranged from 0.5-2.1 hours.

The third stage, from the time the calf was born until the placenta was expelled, was recorded (within the 6 hours observed) for 13 of the 20 cows. The median duration was 3.3 hours but this ranged quite widely from 1.9-5.6 hours.

The average times taken for cows to stand and lick their calf after calving, and latencies of calves to stand and suckle are summarised in Table 4.02.

Table 4.02 Latencies of events after calving

	n	Minimum	Maximum	Median
Cows stands	20	0 min	21.2 min	0.5 min
Cow licks calf	20	0.1 min	6.53 min	0.6 min
Calf stands	20	0.3 hours	3.0 hours	0.8 hours
Calf sucks	14	0.7 hours	5.3 hours	2.3 hours

4.3.3 Differences between calving and control observations

The number of lying bouts (defined as periods of lying, separated by periods of standing or walking) increased significantly between the pre-calving control and calving observations ($W = 166.5$, d.f. $= 19$, $p < 0.001$). This change in the daily average is shown in Figure 4.02.

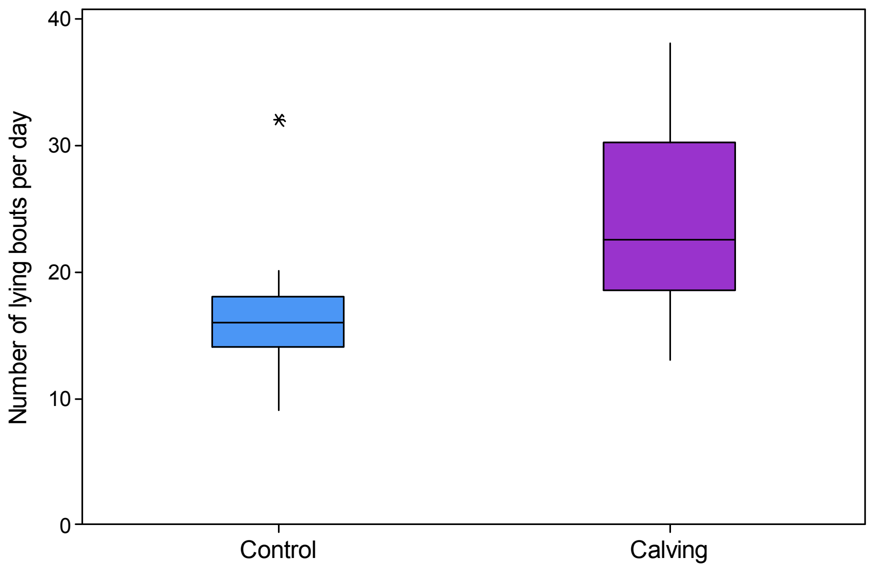

Figure 4.02
Box plots of the daily number of lying bouts during the calving and control observations. This was significantly higher on the day of calving.

The average daily lying duration also showed a significant change between the two observations ($t = -2.81$, d.f. = 19, $p = 0.011$). Lying duration decreased from 13.6 hours per day during the control to 12.6 hours the day before calving (Figure 4.03).

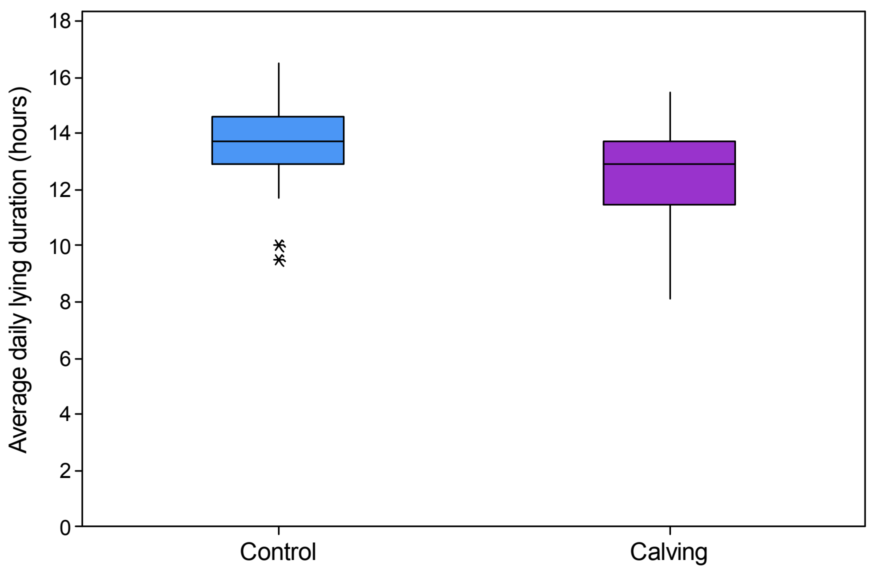

Figure 4.03
Box plots of daily lying durations during the calving and control observations. The duration of lying was approximately an hour shorter during the day before calving.

The daily number of walking bouts (defined as periods of walking, separated by periods of standing or lying) was significantly higher during the calving compared to the pre-calving control observation ($t = 3.31$, d.f. = 19, $p = 0.004$). This can be seen in Figure 4.04.

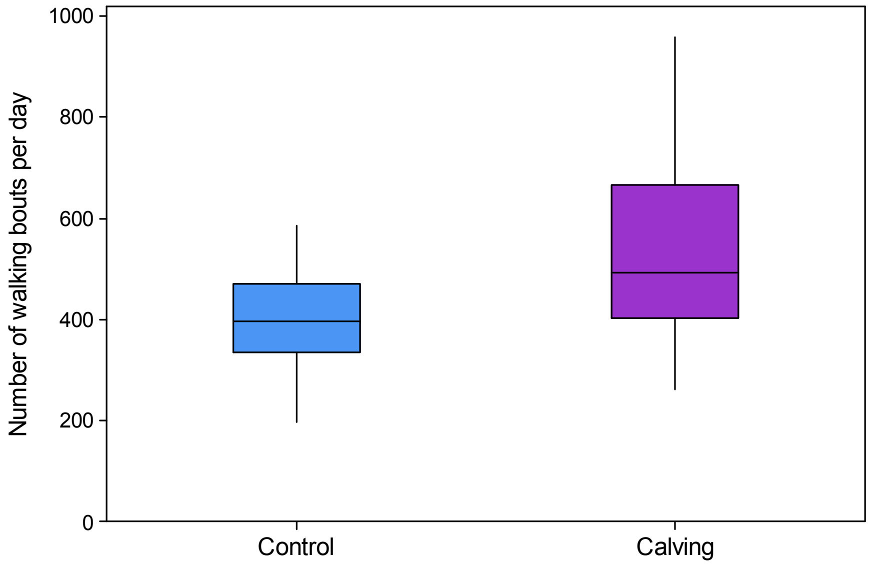

Figure 4.04
Box plots of daily walking bouts during the calving and control observations. Although there was a lot of variation, cows walked significantly more on the day of calving.

The daily walking duration showed a significant difference between the calving and control observations (t = 3.70, d.f. = 19, $p < 0.001$). Cows spent an average of 31.5 minutes walking the day before calving, compared to 21.0 minutes during the pre-calving control day (Figure 4.05).

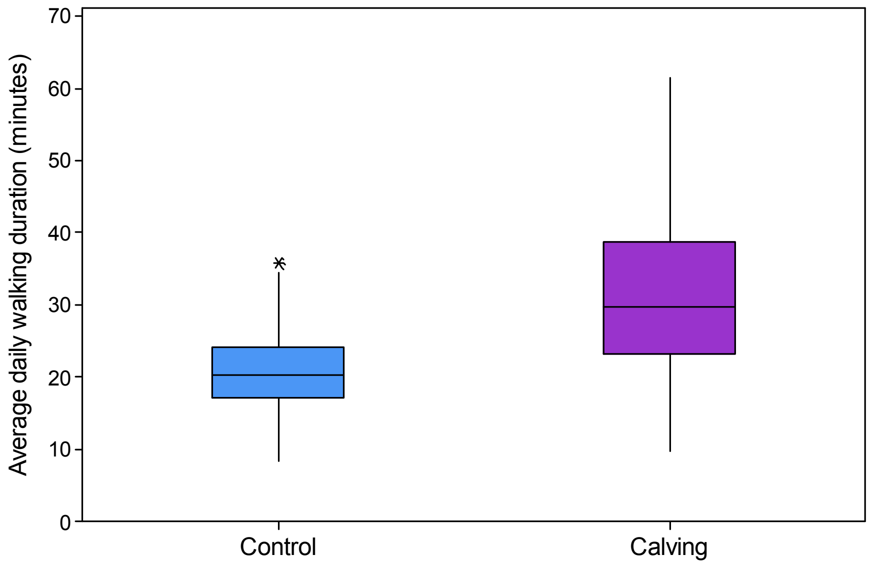

Figure 4.05
Box plots of walking durations during the calving and control observations. This increased by around 50% from around 20 minutes per day to over 30 minutes a day during the day prior to calving.

Cows were observed to raise their tail more often during the calving observation than the control period (W = 209.0, d.f. = 19, $p < 0.001$). This is shown in Figure 4.06.

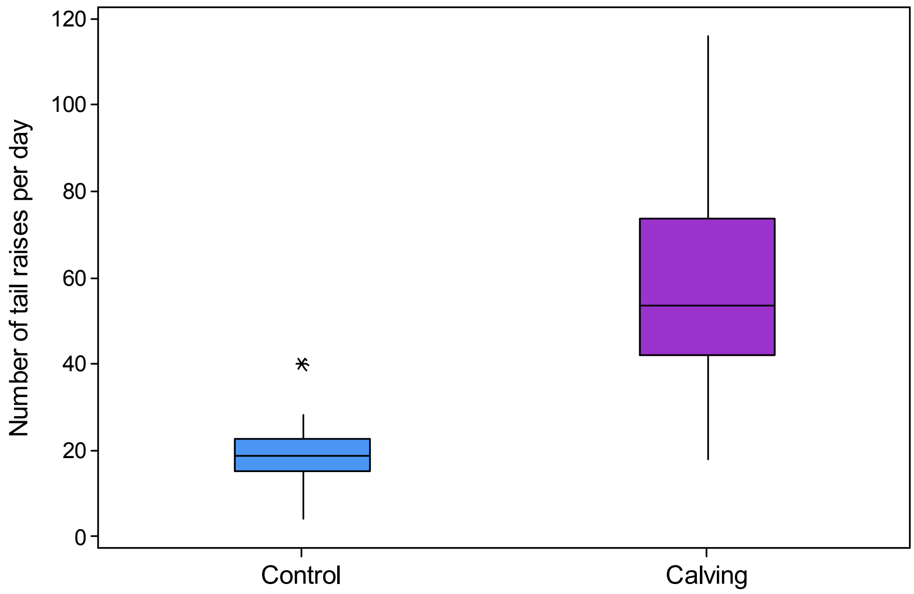

Figure 4.06
Box plots of the number of tail raises during the calving and control observations. This was significantly higher on the day of calving.

The duration that cows spent eating was shorter on the day before calving (with an average duration of 1.7 hours) than during the control period (average duration 2.0 hours). However, this difference was not statistically significant (t = -1.46, d.f. = 19, p = 0.160).

The daily ground licking duration was significantly longer during the calving than the control observation (W = 172.5, d.f. = 19, p = 0.012). Cows spent a median duration of 4.8 minutes licking the ground during the day before calving and only 0.8 minutes during the control observation (Figure 4.07).

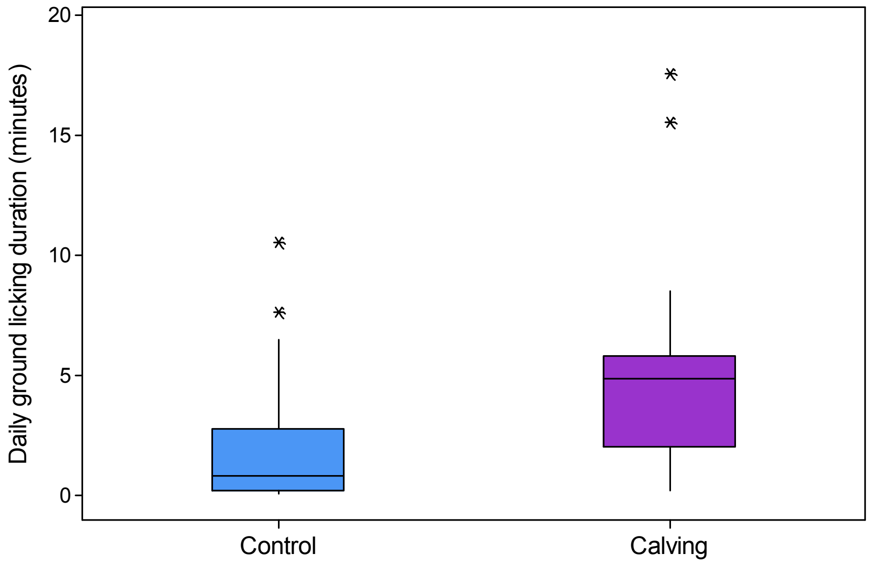

Figure 4.07
Box plots of ground licking durations during the calving and control observations. There was a significant increase in the time cows spent licking the ground on the day of calving.

All of the daily frequencies and behaviours, with the significance of any differences between them, are summarised in Table 4.03.

Table 4.03 Summary of the mean (± S.D.) control and calving values for each of the daily frequencies and behaviours recorded before calving, with the significance level of the difference between them

Behaviour	Control values	Calving values	Significance
Lying frequency (no.)	16.4 ± 4.8	24.2 ± 6.8	***
Lying duration (hours)	13.6 ± 1.8	12.6 ± 1.8	*
Walking frequency (no.)	388.0 ± 105.1	529.3 ± 186.9	**
Walking duration (minutes)	21.0 ± 7.4	31.5 ± 13.1	***
Tail raising frequency (no.)	19.1 ± 7.6	59.3 ± 24.9	***
Eating duration (minutes)	118.7 ± 47.4	102.1 ± 48.2	n.s.
Ground-licking duration (minutes)	2.1 ± 3.0	5.2 ± 4.4	*

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.3.4 Analysis of six-hour periods before calving

All of the behaviours included in the 24-hour analyses showed significant changes during at least one of the six-hour periods before calving. Changes were seen throughout the time period studied but the majority of the differences were observed during the final six hours.

The median lying frequency was four bouts per six hours during all of the control periods with no significant differences between periods (Friedman's Q statistic = 1.16, df = 3, p = 0.763). When the four calving periods were compared, the number of lying bouts during the final six hours before calving was significantly higher than the other periods (Q = 39.58, df = 3, p < 0.001). This difference can be seen in Figure 4.08. s

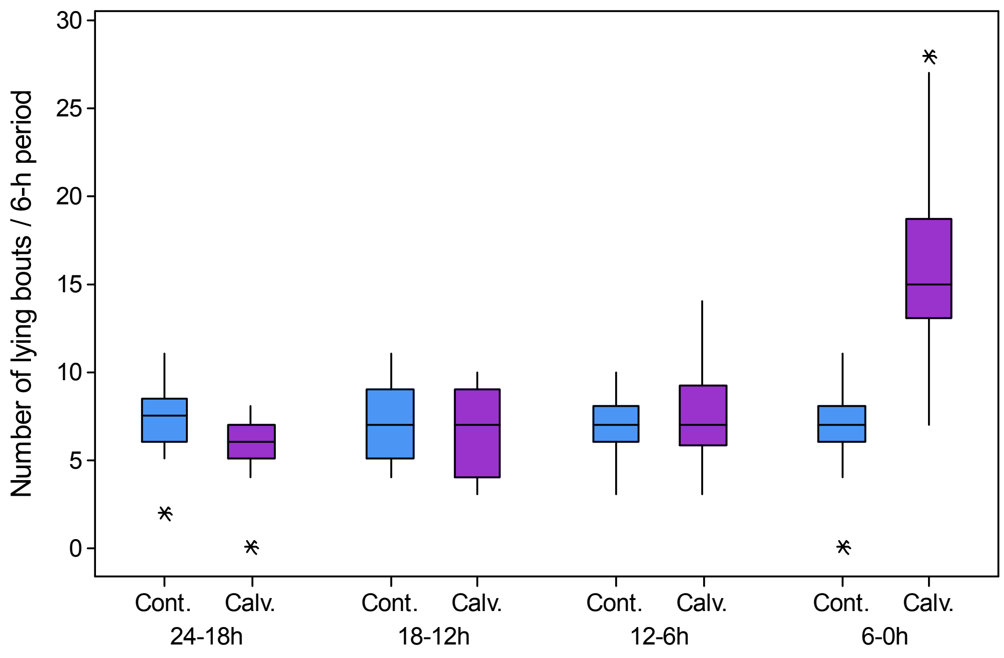

Figure 4.08
Box plots of lying frequencies before calving and during the control observation. A significant increase was observed during the final six-hour period of the calving observation.

There were significant differences between each of the four six-hour calving and control periods ($Q = 39.81$, $df = 3$, $p < 0.001$). The variable tested was the change within each individual cow. For lying frequency during the final six-hour period, this was consistent between cows and all 20 showed an increase of ≥2 bouts (Figure 4.09).

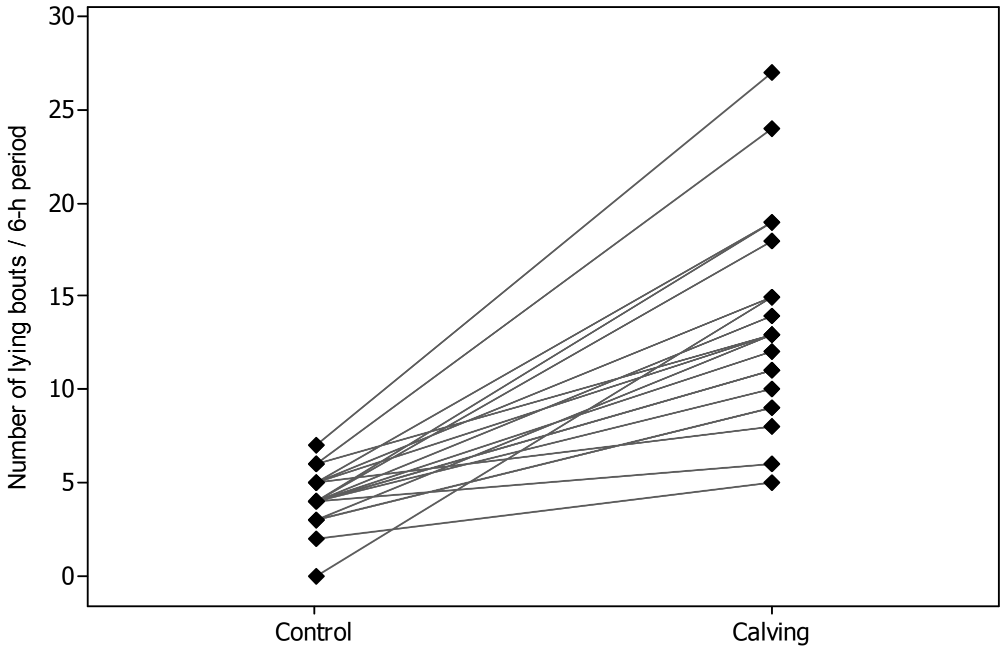

Figure 4.09
The direction of change in the number of lying bouts during the final six hours before calving compared with the control was the same for all of the cows studied. Each line links the values for an individual cow.

The median lying durations during the control observations were all between 3-4 hours of the six-hour periods and there were no significant differences between the six-hour periods ($Q = 1.14$, $df = 3$, $p = 0.767$). The lying durations were generally shorter during the six-hour calving periods than during the control periods but the differences between the calving periods were not significant ($Q = 7.62$, $df = 3$, $p = 0.055$). Within-individual differences between calving and control observations were significantly different between the six-hour periods ($Q = 8.70$, $df = 3$, $p = 0.034$) with reduced lying durations from 6-18 hours before calving (Figure 4.10).

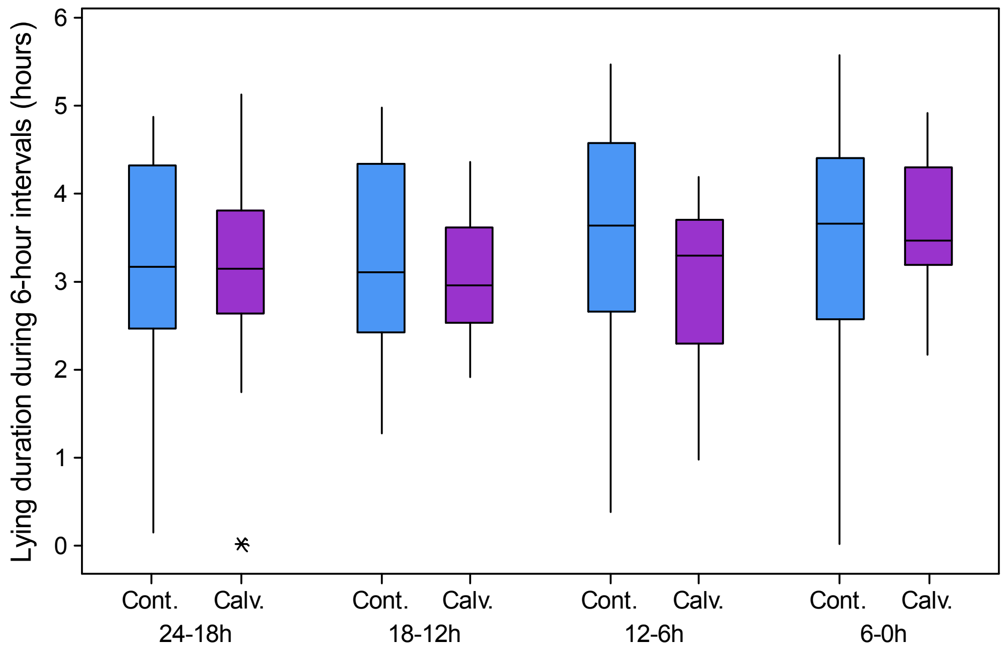

Figure 4.10
Box plots of lying durations during each six-hour period for calving and control observations. There were no differences between the four control periods but the within-individual differences varied significantly between periods.

The median walking frequency during the control periods varied from around 70 bouts per six hours, to just over 100 bouts. None of the control periods were significantly different from the others ($Q = 4.12$, $df = 3$, $p = 0.249$) and no significant differences were found between the four calving periods ($Q = 2.80$, $df = 3$, $p = 0.423$). Also, there was no significant difference between the calving and control periods ($Q = 4.86$, $df = 3$, $p = 0.182$).

The median duration of walking was similar and not significantly different between the four control periods (Q = 3.00, df = 3, p = 0.392) and the walking duration during the calving periods did not differ significantly from each other (Q = 1.98, df = 3, p = 0.577). The individual differences in walking duration between the calving and control observations were not significantly different between the four six-hour periods (Q = 4.56, df = 3, p = 0.207).

The frequency of tail raises was consistent between the four control periods, with a median of 4-5 tail raises per six hours. These were not significantly different from each other (Q = 0.41, df = 3, p = 0.939), whereas there was significant variation between periods before calving (Q = 40.56, df = 3, p < 0.001). The post-hoc test indicated that, the period from 0-6 h before calving was significantly different from the other periods. The results for the difference between calving and control observations were the same as those of the calving periods alone (Q = 34.85, df = 3, p < 0.001). This clear increase from 0-6 h before calving can be seen in Figure 4.11.

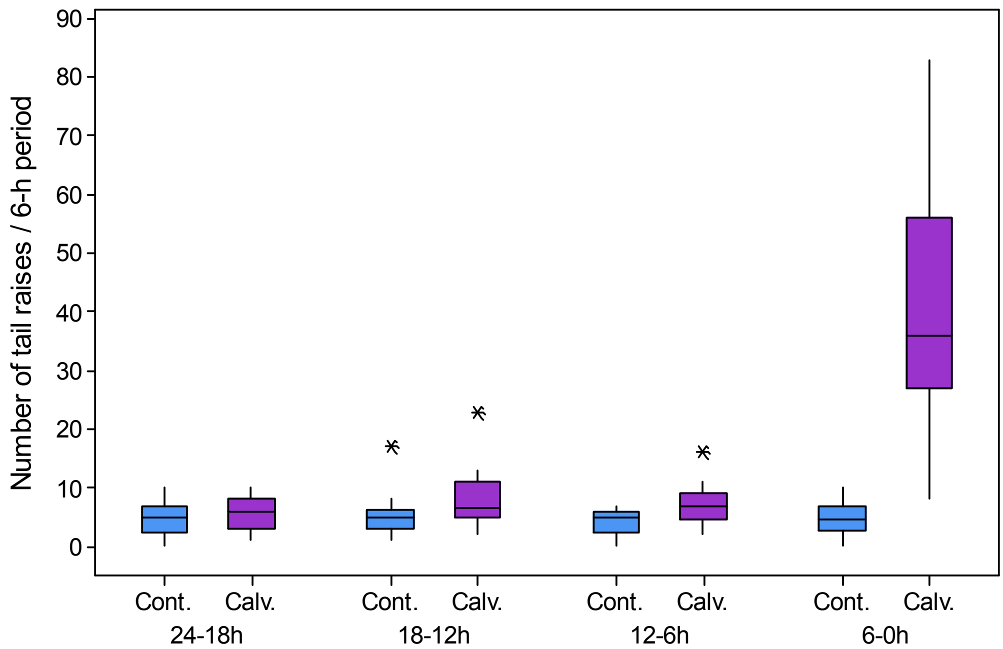

Figure 4.11
Box plots of the number of tail raises during each six-hour period for calving and control observations. A significant increase was observed during the final six-hour period of the calving observations.

Similar to the number of lying bouts, the direction of change in the frequency of tail raises was relatively consistent between individual cows in the final six hours before calving (Figure 4.12).

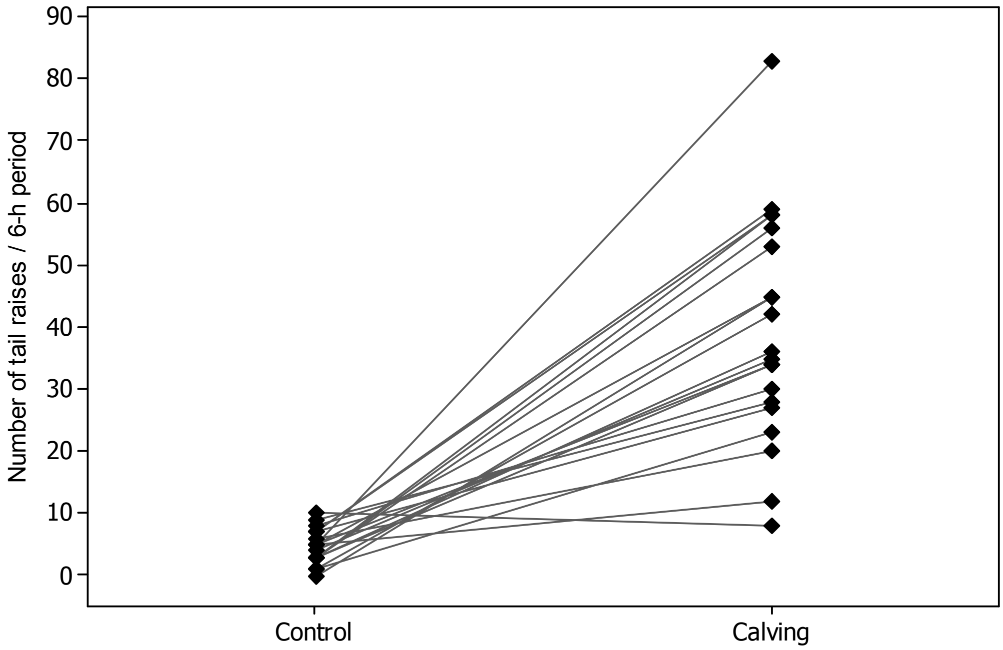

Figure 4.12
The number of tail raises was significantly higher during the final six hours before calving, compared with the control. Each line shows the change for an individual cow. The direction of this change was the same for 19 out of 20 of the cows in this study.

The duration of eating did not vary significantly between the control periods, although the median duration varied from 16-30 minutes of the six-hour period ($Q = 6.48$, $df = 3$, $p = 0.090$). Significant differences were found between the six-hour periods before calving ($Q = 23.22$, $df = 3$, $p < 0.001$). The post-hoc analysis showed that there was no difference in eating duration between 18-24 h and 12-18 h before calving but these were significantly different from the other periods. When the calving and control eating durations were compared, no significant differences were observed until the final six hours. During the final six hours the median duration of eating was significantly shorter than during the other periods ($Q = 7.80$, $df = 3$, $p = 0.050$). Figure 4.13 shows the values for the duration of eating.

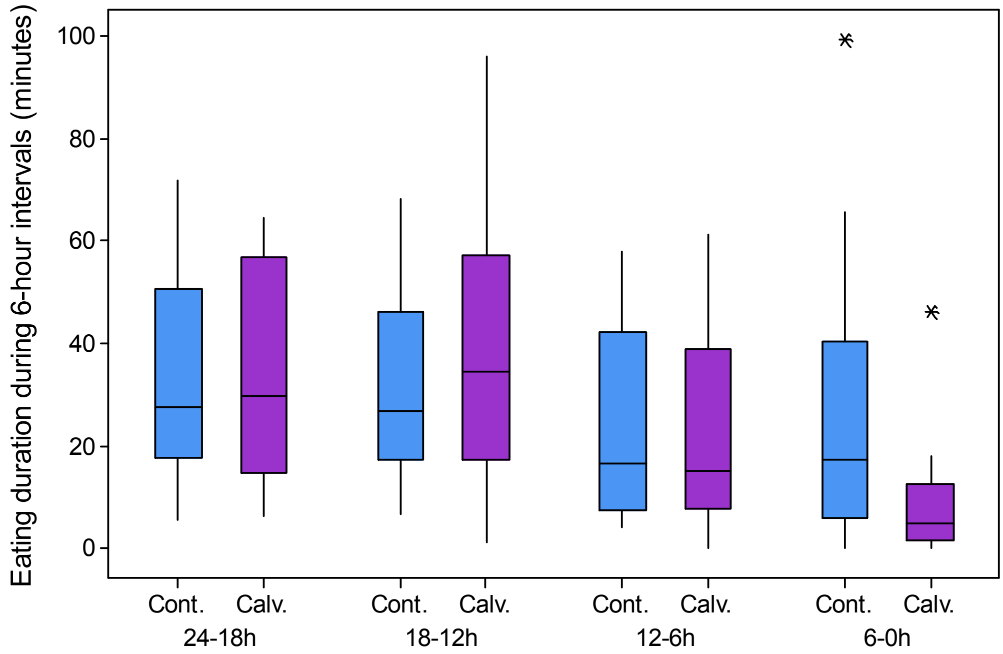

Figure 4.13
Box plots of eating durations during each six-hour period for calving and control observations. Significantly shorter eating durations were observed during the final 12 hours before calving.

The duration of ground licking was very short throughout the control observations, with median values of 14 seconds or less during a six-hour period. There were no significant differences between these periods ($Q = 2.66$, $df = 3$, $p = 0.448$). Ground licking duration varied significantly between the four six-hour periods before calving ($Q = 31.07$, $df = 3$, $p < 0.001$). The post-hoc analysis showed that the period from 0-6 h before calving was significantly different from the other six-hour periods. The analysis of the individual differences between calving and control observations showed a similar significant difference (Q = 16.52, df = 3, $p < 0.001$). These data can be seen in Figure 4.14.

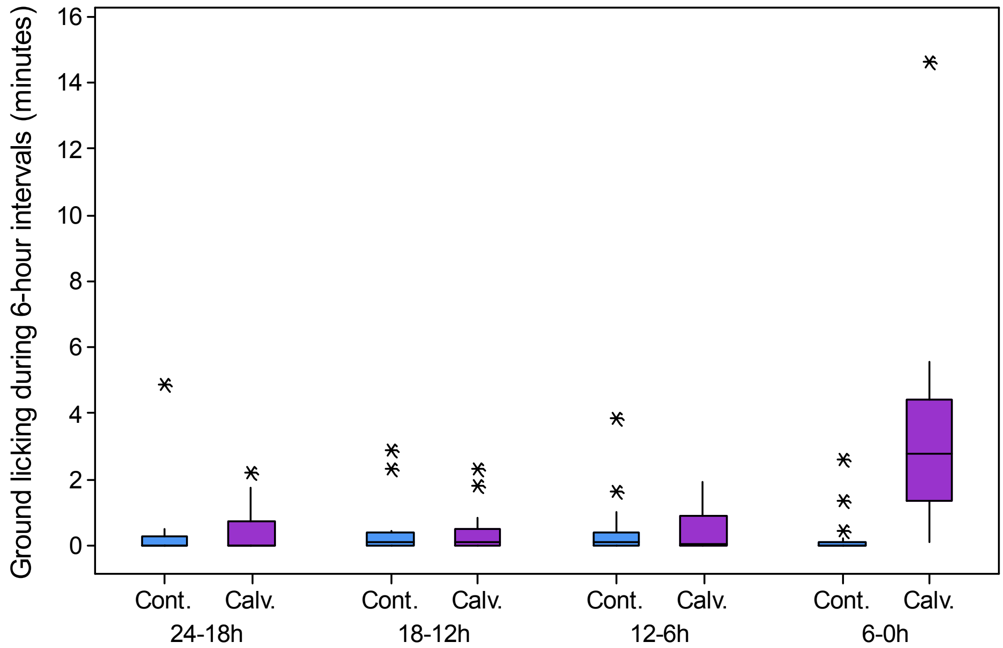

Figure 4.14
Box plots of ground licking durations during each six-hour period for calving and control observations. This increased significantly during the final six-hour period before calving.

The results for each individual were shown for the four most consistent changes in behaviour during the last six hours before calving (difference between calving and control values) and summarised in Table 4.04.

Table 4.04 Summary of the individual differences in the behaviour of 20 cows between calving and control observations. The signs (+ or -) show the direction of the change (calving-control) and the colours show whether the direction of change for an individual cow followed (green) or did not follow (orange) the average response of the group

Cow ID	Number of lying bouts	Number of tail raises	Duration eating (minutes)	Duration licking ground (minutes)
4	+ 7	+ 40	- 0.7	+ 0.2
13	+ 7	+ 14	- 34.7	+ 3.8
30	+ 2	+ 22	- 13.2	+ 1.1
47	+ 10	+ 53	- 36.3	+ 1.8
51	+ 3	+ 19	- 42.5	+ 2.4
53	+ 6	+ 33	- 4.8	+ 1.0
80	+ 10	+ 55	- 48.9	+ 14.6
85	+ 15	+ 52	- 20.7	+ 2.8
101	+ 8	+ 78	+ 13.7	+ 4.0
122	+ 14	+ 31	- 53.1	+ 1.3
130	+ 15	+ 45	+ 4.7	+ 4.7
136	+ 14	+ 41	- 6.6	+ 4.8
156	+ 20	+ 50	+ 14.0	+ 4.3
187	+ 7	+ 31	- 6.3	- 1.3
189	+ 6	- 2	- 50.8	- 0.1
191	+ 6	+ 7	- 64.2	- 7.8
205	+ 10	+ 29	- 13.1	+ 5.4
207	+ 18	+ 51	- 13.6	+ 3.3
216	+ 3	+ 22	- 9.5	- 5.0
248	+ 8	+ 20	- 32.5	+ 1.8

4.3.5 Time before calving when behaviour changed

The number of lying bouts per hour was estimated to increase from approximately 4 hours 13 minutes before calving. This breakpoint between the regression lines explained 49.9% of the variance. The raw data with separate regression lines for data before and after the estimated break are shown in Figure 4.15.

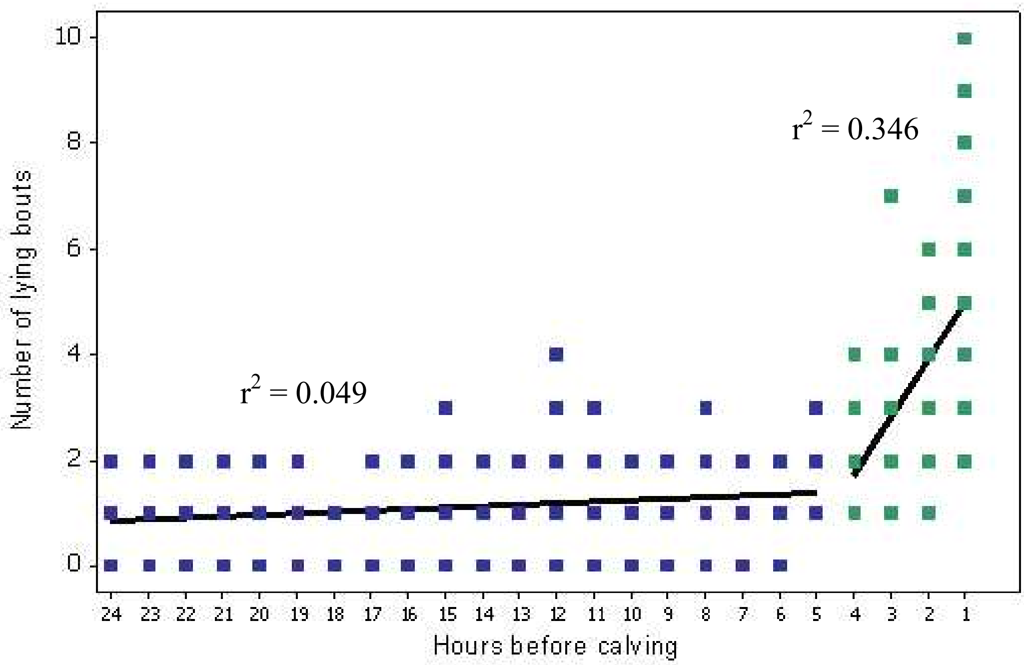

Figure 4.15
Separate regression lines for the hourly number of lying bouts from 24 to 5 hours before calving and from 4 hours before until calving. During the final four hours before calving, a steeper slope provides a better fit for the data.

Lying duration remained fairly constant throughout and the break point calculated only explained 2.2% of the variance in the data so is not likely to be important, or a useful predictor of calving.

There was no change in the slope of the walking frequency data that explained more of the variance than a single line. The walking duration did not change until around 5 hours 13 minutes before calving, when a slight increase was observed. However, this only explained 10.6% of the variance.

For the number of tail raises, the trend was similar to that seen for lying frequency. Again there was no change against time from 24 hours before up to 6 hours 20 minutes before calving, after which the slope increased. This break in the data explained 54.5% of the variance in the data and is shown in Figure 4.16.

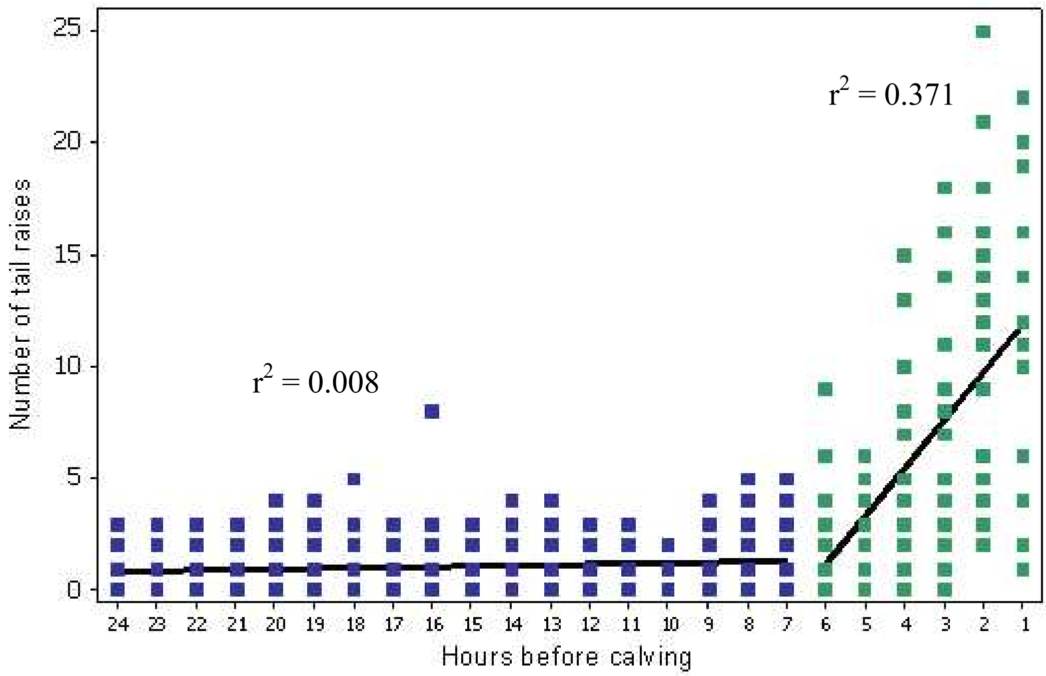

Figure 4.16
Separate regression lines for the hourly number of tail raises from 24 - 7 hours before calving and from six hours before until calving. During the final six hour before calving, the regression line of the data shows a positive increase.

The duration of eating was tested as the proportion of standing time spent eating, to ensure that it was independent of any changes in lying duration. This increased slightly until the estimated break point at 15 hours 40 minutes before calving and decreased after this point, but this regression only explained 13.9% of the variance in the data.

The time cows spent licking the ground remained constant until around 3 hours 19 minutes before calving, when it started to increase. This break between the regression lines explained 42.7% of the variance (Figure 4.17).

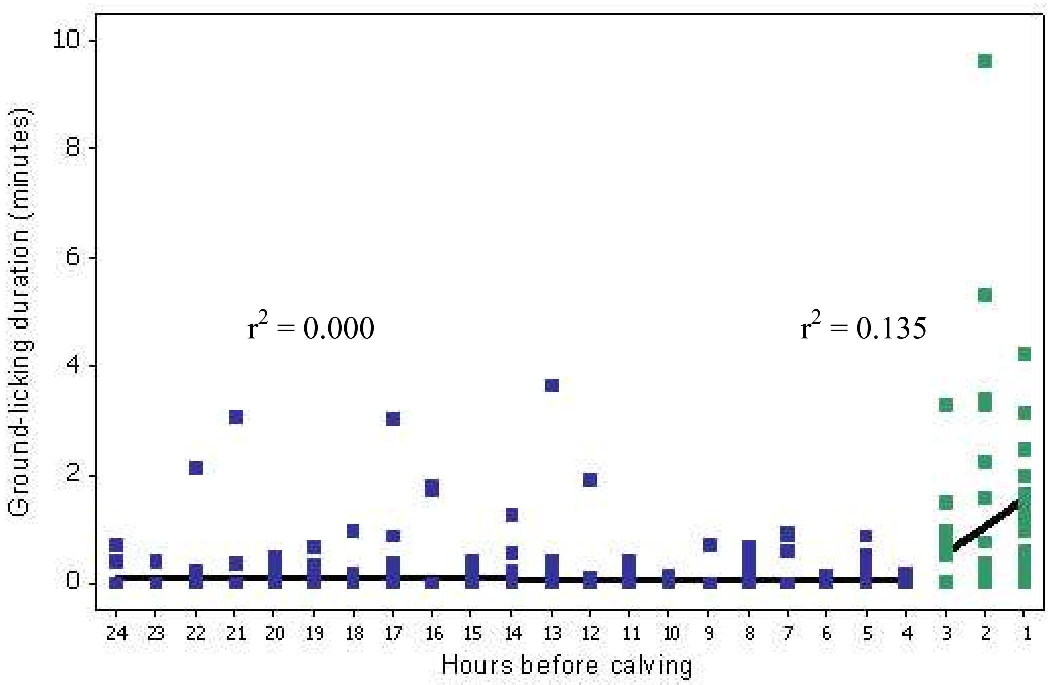

Figure 4.17
Separate regression lines for the hourly ground-licking duration from 24 - 4 hours before calving and from three hours before until calving. The regression line is positive for the data from the final three hours before calving. However, the single outlier may have a large influence on this result.

The time and variation explained by these changes is summarised in Table 4.05.

Table 4.05 Break points and the percentage of variance explained by segmented regressions for each behavioural variable studied

	Break point time	Variance explained (%)
Lying frequency	4.2 h	49.9
Tail raising frequency	6.3 h	54.4
Lying duration	9.1 h	2.2
Walking duration	5.2 h	10.6
Eating duration	15.7 h	13.9
Ground-licking duration	3.3 h	42.7

The control observations were tested for significant breakpoints in lying frequency, tail raising frequency and ground licking duration. None of these segmented regressions explained more than 1% of the variance.

4.4 Discussion

The durations of the stages of parturition and latencies of events after calving were recorded for later comparison with results from heifers and assisted calvings. The durations of the second stage of parturition were in agreement with those observed in the literature, with a shortest duration of about 30 minutes and median of an hour. The longest observed in this group of cows was just over two hours which is within the maximum duration of four hours stated by Ball and Peters (2004). The shortest time recorded for the completion of the third stage of parturition was 1.9 hours, which is close the minimum of the 2-6 hour range expected (von Keyserlingk and Weary, 2007). The longest time observed before the placenta was expelled (within the six-hour period studied) was 5.6 hours and the median was 3.3 hours.

One cow calved while standing but the rest were all lying at the time when the calf was expelled. The median duration for cows to stand after calving was only 32 seconds and only three remained lying for more than two minutes after giving birth. All of the cows started licking their calves very soon after they stood up or could reach their calf. The latencies fell well within the first several minutes after birth, as was expected (von Keyserlingk and Weary, 2007). The time taken for calves to stand and suckle for the first time varied greatly and will be discussed in the following chapter when looking at differences between calving in heifers and those that are assisted.

The control observations were matched with the calving observations for time of day but were not all made the same number of days before calving. This may have introduced some variation into the control data, as it is likely that some behaviour may change progressively throughout the final week before calving. However, significant differences were still observed between the calving and control observations so it is not likely that this was a problem. The behaviour during the final day before calving was of the most interest in this case, and the additional observations during late gestation were simply for use as controls to compare the behavioural changes close to calving against.

Eight of the cows in this part of the study were moved to individual pens during the final few days before they calved to improve the chances of obtaining a good video record of the calving and post-calving events. None of these cows were moved during parturition and the individual pens were adjacent to and within view of the rest of the group so it is unlikely that this would have disturbed them at this time and extended the duration of parturition.

There were more lying bouts during the day before calving than during the control observations. The control values ranged from 9-32 bouts per day, with a mean of 16.4, which is comparable but slightly higher than those found by Blackie *et al.* (2006). This study measured the average daily lying frequencies of 24 cows during the first, sixth and twelfth weeks of lactation as 12.6, 14.2 and 11.9 bouts per day, respectively. The increase at calving was to an average of 24.2 lying bouts per day. This agrees with the findings of Huzzey *et al.* (2005) who identified an increased number of standing bouts on the day of calving, compared with the days before and after. Standing bouts were defined as the interval between two lying events, making it comparable with results for the number of lying bouts. The increase at calving was to 17.3 bouts, compared with 11.7 bouts on average the day before and 13.1 bouts the following day. This increase in transitions between standing and lying is likely to be a measure of the restlessness associated with the first stage of parturition (Owens *et al.*, 1985), which may be why it was only observed within the final six hours before calving when the data were analysed in shorter six-hour periods. This suggests that the overall daily changes that were observed were mainly a result of this increase within the final six hours before calving. This is consistent with the results of the segmented regression that found a change in the slope of the data at 4.2 hours before calving. The number of lying bouts increased in the last six hours before calving in all of the cows, potentially making it a very useful indicator of calving.

The daily duration of lying was significantly shorter the day before calving than during the control. This dropped from 13.6 hours a day to 12.6 hours. Huzzey *et al.* (2005) recorded the daily lying durations of fifteen Holstein cows for 10 days before and after calving and also found a decrease in lying time on the day of calving. An average daily duration of 9.6 hours was recorded on the day of calving, compared with 11.7 hours in the days before this and 10.6 hours a day following calving. This was a more pronounced decrease than that observed in this study, but there is no information regarding any assistance required. It is possible that assisted cows show a larger decrease in lying duration before calving and that this might explain the difference seen here. The control daily lying durations were longer than the averages measured in lactating Holstein-Friesians kept on slatted (12.2 and 11.2 hours per day) and grooved floors (12.6 and 12.4 hours per day) (Stefanowska *et al.*, 2001). Blackie *et al.* (2006) also recorded shorter average daily lying durations in Holsteins of 10.3, 9.2 and 10.7 hours during the first, sixth and twelfth weeks of lactation, respectively. When six-hour periods were analysed, no differences were found between the four six-hour periods of the control observation but there was some variation in lying duration between the periods the day before calving. The main difference appeared to be that less time was spent lying between 6-18 hours before calving, before lying duration increased in the final six hours. As there was no point after which lying duration increased until the time of calving, the breakpoint that was calculated for this variable explained very little variation in the data.

The daily walking frequency was significantly higher the day before calving when compared to the control observation. However, no differences were observed when shorter periods of six hours were analysed. Also, no break point in the data could be calculated using the segmented regression method. The increased daily average is again likely to be associated with restlessness during the first stage of parturition but as this could not be determined from the six-hour periods it may not be a useful short-term predictor of calving. The results were very similar for the duration of walking, with cows walking for longer on the day before calving. When this was analysed in shorter six-hour periods, no differences were found and the breakpoint that was calculated did not explain much of the variation.

The number of tail raises increased significantly the day before calving. The average number of tail raises during the daily control observations was 19.1, which was comparable with the results of another study of tail raises during late gestation. An automatic sensor was used by Bueno *et al.* (1981) that counted daily averages of 27.6 ± 2.4 (S.D.) tail raises five days before calving and 26.9 ± 3.1 (S.D.) two days before. The six-hour period analysis showed no differences between the control periods but of the four calving periods, the number of tail raises in the last six hours before calving was significantly higher than the others. This is in agreement with the calculation of the break point at around six hours. Nineteen of the 20 cows raised their tail more frequently during calving. This was one of the most consistent changes observed across cows making it a potentially useful indicator of calving. However, measuring the frequency of tail raises might not capture the cows that keep there tail raised for long periods of time but do no relax and lift them again repeatedly. For this reason, the recording of tail raising was changed for the next part of the study by recording the times when the tail was lowered to give the duration. Wehrend *et al.* (2006) observed changes in the tail posture in all of the cows in their study of behaviour prior to parturition. Tail raising is also mentioned as a sign of calving in other publications but is not quantified in these cases (Owens *et al.*, 1985; Lidfors *et al.*, 1994; Phillips, 2002).

Eating duration was not different between the 24-hour observations (control versus calving) but changes were observed between the shorter six-hour periods. There was no variation between the control periods, but many differences were found between the four six-hour periods before calving. However, the within-individual changes between calving and control observations were probably the most useful result, with significantly less eating during final six-hour period. The breakpoint did not explain much variation in this behaviour but the reduction in eating during the final six hours may be a useful predictor of calving, especially if used in combination with other behavioural signs. Changes in feeding behaviour were expected to be observed as these have been reported in previous studies. Although during this study a significant decrease in eating was found overall during the final six hours before calving, there was a lot of variation between individual cows and three showed an increase in eating duration during this time. In a seven-week study, Bao and Giller (1991) found a regular decline in weekly feeding durations from at least three weeks before calving. Also in shorter studies, during the last two weeks before calving, decreases in daily feeding duration and dry matter intake (DMI) were reported (Huzzey *et al.*, 2007). Bertics *et al.* (1992) measured an average decrease of 28% in the DMI of 11 Holstein cows fed *ad lib* during the final 17 days before calving. It is likely that the duration of observation used in the current study was not long enough to capture these changes. DMI may be a more accurate measure of feeding as daily feed intake is a result of the rate of eating, in addition to the number of meals eaten and the length of each meal (Grant and Albright, 1995; De Vries *et al.*, 2003). In this case the intensity of eating is unknown, so feeding durations were used to estimate intake.

Ground licking duration showed clear and consistent changes in relation to calving. The daily durations were longer before calving than during the controls. This difference is likely to be due to the increase observed within the final six hours, which is the only time that varied significantly within the six-hour period analysis. The breakpoint in the data explained part of the variation in the data collected on the day before calving and was estimated at around three hours before. However, this result appeared to be largely due to one cow that spent a lot longer licking the ground than the rest. The time when ground licking increased was expected to be around the same time as the water bag bursting at the beginning of the second stage of parturition, when dams will normally lick the birth fluids. The second stage lasted approximately one hour, on average. The time when ground licking was estimated to start increasing was earlier, at three hours before calving, but durations were longest during the final two hours.

The main two behavioural signs of calving identified that showed the highest level of consistency between individuals were the number of lying bouts and the number of tail raises. These relate closely to the two of the most commonly recorded signs noticed by the stockmen in Part 1 of Chapter 3, which were tail lifting and restlessness. In addition to these, the durations of eating and ground licking may also provide useful information regarding the expected time before calving.

Chapter 5: Behaviour before, during and after parturition categorised by parity and calving difficulty

5.1 Introduction

The usefulness of a system for the prediction of calving would be increased if it was able to account for differences that may exist between cows of different parities, and report predictions accordingly. Heifers calving at 24 months of age are not fully grown at the time of their first calving and have no previous experience, making them likely to behave differently to multiparous cows. Calving difficulties may also influence the behaviour of individual cows and it would be valuable to identify any differences in the behaviour of dams experiencing calving difficulties compared to those with normal calvings. If warning signs could be identified from behaviour and detected early enough, this would be very useful for a monitoring system and could allow an alert for assistance to be activated.

5.1.1 Differences between first and successive calvings

Dairy heifers in the UK are normally inseminated when they are 14-16 months old so that they give birth when they are around the age of two years (Wathes *et al.*, 2008). These animals are not yet fully grown and have no previous experience so are expected to differ both physiologically and behaviourally from multiparous dams.

The first stage of parturition tends to be longer in heifers than in multiparous cows (Ball and Peters, 2004) and the behaviours observed at this time are also different. Wehrend *et al.* (2006) used one-zero recording to score a number of behaviours and subjectively classified each individual as calm, restless or very restless. Ten heifers were compared with 68 cows without dystocia. None of the heifers were scored as calm, but 32% of the multiparous cows were. The other difference observed between heifers and cows was that a higher proportion of heifers (80%) pawed with their forefeet than cows (34%). Heifers may show signs of abdominal pain from as early as 24 hours before cervical dilation but there is great variation in the intensity of symptoms of the first stage of parturition and many multiparous individuals show no apparent signs of discomfort. The second stage of parturition is also longer in heifers than in cows (Noakes *et al.*, 2001). The average duration for heifers is 54 minutes, which is more than double the average duration of 22 minutes observed in older dams (Doornbos *et al.*, 1984).

Differences have been described between primiparous and multiparous individuals in the expression and responses to hormones before parturition in sheep and are likely to be similar in cattle. In ewes, the release of oxytocin is stimulated by the distension of the birth canal due to the expulsion of the foetus and accentuates the uterine contractions (Meurisse *et al.*, 2005). Both primiparous and multiparous ewes release oxytocin in response to parturition but the increase in the olfactory bulb is greater in multiparous ewes (Levy *et al.*, 1995). There is also evidence that multiparous ewes have a greater concentration of oxytocin receptors in more areas of the brain (Broad *et al.*, 1999).

5.1.2 Differences between assisted and normal calvings

Extended durations of parturition are often associated with calving difficulties. In one study dystocia was defined by the duration of the second stage of parturition. Assistance was given if this stage continued for longer than two hours without any progress being made. The calves of all of the cows that were assisted were found to have abnormal presentations (Wehrend *et al.*, 2006). The behaviour of nine cows with dystocia was compared with that of 68 cows without dystocia. Higher percentages of cows with dystocia were found to rub against walls (89% compared with 34%), discharge urine (78% compared with 25%), and scrape the floor (89% compared with 24%). Differences between the behaviour of cows with dystocia (defined as requiring assistance by two experienced farm workers) and those with no calving problems were also found by Proudfoot *et al.* (2008). Cows with dystocia had more standing bouts and spent less time eating during the 18 hours before calving than those without any difficulties.

5.1.3 Maternal behaviour of inexperienced dams and following difficulties at calving

Heifers can take longer to express maternal behaviour following calving as they have no previous experience and fewer receptors for the hormones involved in the initiation of maternal behaviour (Dwyer, 2008). Failure to lick the calf is more common in heifers than in multiparous dams (von Keyserlingk and Weary, 2007).

Cows can take longer to stand up and start licking their calf following difficult calvings, due to the discomfort and exhaustion experienced (Houwing *et al.*, 1990). However, the time to stand can be delayed if the calf is moved within licking distance of the dam after she has been assisted (von Keyserlingk and Weary, 2007). The experience of a difficult calving may also have a negative effect on the calf and it is possible that these calves will take longer to stand and suckle for the first time. In sheep, lambs that were assisted at birth were slower to stand up and suckle than unassisted lambs (Dwyer, 2003) so a similar effect may be seen in calves.

5.1.4 Research aims

The overall aim of this chapter was to identify any differences in behaviour before calving between cows and heifers, and between those that are given assistance at calving and those that are not.

This was divided into more specific research aims, listed below;

5. To compare the durations of the stages of parturition between cows and heifers, and assisted and unassisted births.

6. To identify which behaviours show changes prior to calving that are not observed during control observations, and investigate how these differ between cows and heifers that calve with and without assistance.

7. To examine when changes occur in two-hour periods between calving and control observations and see how this varies between cows and heifers, that are assisted or not at calving.

8. To compare the latency of events following parturition between cows and heifers, and assisted and unassisted births.

5.2 Methods

5.2.1 Selection of focal individuals

The calving difficulty scores from the farm records were used to help select individuals for behavioural analysis of video recordings. Unassisted cows with deliveries scored as normal (no assistance or unobserved) were used as the easy calving group. However, the selection of cows for the assisted calving group was less simple as some of the cows might have calved successfully without assistance, if they had been unobserved. Therefore, those with deliveries scored as jack (jack used or assisted by two men) were selected and the duration of assistance was also measured. Assisted calvings were used if assistance with the jack took longer than one minute.

Cows were selected so that the assisted and unassisted groups had comparable average parities. The age at first calving (AFC) was recorded for heifers. Cows that calved on dates when there were problems with the video recordings were not used and preference was given to focal cows that could be seen clearly on the videos. Priority was given to cows for which there was corresponding accelerometer data for the work described in Chapter 6.

5.2.2 Collection of behavioural data

The methods used to record and analyse behaviour from video recordings were described in detail in Chapter 2. From the results from Chapter 4 it was decided that observations over a shorter time before calving would be adequate, so a revised duration of 12 hours before calving was investigated.

Specifically recorded landmark calving events were used to calculate the durations of the second and third stages of parturition. These were the time when the water bag burst (start of stage two), the time when the calf was expelled (end of stage two and start of third stage) and the time when the placenta was expelled (end of third stage). The duration of the first stage was not calculated because it was not possible to record the time when it started.

Each cow was studied for 12 hours up to the time when the calf was fully expelled to capture the behaviour before and during calving,. This was known as the calving observation. A control observation was also made for each cow 1-4 days (median = 3) earlier than the calving observation, to allow comparisons to be made. As the cows did not all calve at the same time of day, the times of the control observations were matched to the calving observations for each cow to minimise any effect of circadian patterns in behaviour. In addition to the behaviours studied in Chapter 4, the duration of tail raising was also included. The full ethogram with definitions for each of the behaviours is given in Chapter 2.

The times when each cow stood and licked her calf after delivery were recorded, as were the latencies of the calf standing and suckling. These events following calving were only observed for six hours after birth because if calves are going to suck without help they are likely to do so within this time (Wesselink *et al.*, 1999).

5.2.3 Statistical analyses

The durations of the second stage of parturition were log transformed (to achieve a normal distribution) before they were compared between cows and heifers that were assisted or not. The durations of the third stage were normally distributed so did not require any transformation. These two variables were analysed for differences between parities and assistance required using general linear models (GLM).

Differences in total durations and frequencies of behaviours between the 12-hour calving and control observations were tested using general linear mixed models with penalised quasi-likelihood. This analysis was run in R (R Development Core Team, 2006) with cow identification number included as a random factor, parity (cow or heifer) and calving difficulty (assisted or not) included as factors and the interaction between parity and calving difficulty. The frequency data were tested against a Poisson distribution and durations were fitted with binomial models. Observations with missing data were not excluded from this analysis.

To narrow down the times of changes within the 12 hours before calving, the frequencies and durations of behaviours were calculated for each of six two-hour periods within the observations. Of the total of 288 periods, 12 periods with missing data were excluded from the analysis. Within calving and control observations, the differences between the six periods were tested using a general linear model (GLM) or Friedman's tests, depending on whether the data were normally-distributed or not. Individual identification numbers were included as random factors for the GLM analyses and as blocks for the Friedman's tests. Where significant results were found, appropriate post-hoc tests were used to determine where these differences occurred (Zar, 1999).

Summary data were also collected for the latency of events after calving. The latencies of cows to stand after calving and to start licking their calves were compared between the four groups using Kruskal-Wallis tests, which are the non-parametric equivalent of the analysis of variance (ANOVA). A Mann-Whitney test was used to examine differences in the time taken for assisted and unassisted dams to start licking their calves, without looking at parity. The times taken for calves to stand and suck for the first time were tested for differences between the four groups using Kruskal-Wallis tests.

All means are reported with their standard deviation and medians with their inter-quartile range (IQR), unless stated otherwise.

5.3 Results

5.3.1 Summary of data collected

The experimental design required the analysis of 576 hours of video recordings (two 12-hour observations of each of 24 individuals). During 11 hours of these observations the focal cow was out of sight and two hours of video were missing due to equipment problems. The gaps in the behavioural observations for each individual are summarised in Appendix B. Missing data were not accounted for in the comparisons between 12-hour totals but periods with missing data were excluded from the statistical analyses of two-hour periods. Some details of the cows observed for this part of the study and details of their calvings are given in Table 5.01.

Table 5.01 Summary information about the calvings observed (* denotes missing values)

ID	Parity	AFC (months)	Degree of assistance	Calf sex	Sire	Notes
100	3	-	Normal	Female	Dairy	
138	3	-	Normal	Female	Dairy	
157	4	-	Normal	Female	Dairy	
195	3	-	Normal	Female	Dairy	Twins, milk fever, died of *E.coli* mastitis
236	3	-	Normal	Male	Dairy	
246	2	-	Normal	Female	Dairy	
7	5	-	Jack	Male	Dairy	
81	4	-	Jack	Female	Dairy	
92	4	-	Jack	Female	Dairy	
109	4	-	Jack	Female	Beef	Milk fever
154	3	-	Jack	Male	Dairy	
201	2	-	Jack	Female	Dairy	
177	1	23.2	Normal	Female	Dairy	
233	1	23.3	Normal	Male	*	
257	1	24.3	Normal	Female	Dairy	
305	1	22.7	Normal	Female	Dairy	
314	1	23.7	Normal	Female	Dairy	
320	1	24.4	Normal	Female	Dairy	
98	1	23.9	Jack	Male	Dairy	Calf died
208	1	24.6	Jack	Male	Dairy	
215	1	24.3	Jack	Male	Dairy	
294	1	23.4	Jack	Female	Dairy	
297	1	22.2	Jack	Female	Dairy	
298	1	23.2	Jack	Female	Dairy	

The unassisted cows had a mean parity of 3 (range 2-4) and the assisted group had a mean parity of 3.7 (range 2-5). There was enough similarity and overlap between the parity of the two groups for these to be considered the same when comparing them for differences in behaviour. The assisted heifers were 23.6 ± 0.9 months old at calving and the unassisted heifers were 23.6 ± 0.7 months old. These two groups did not have significantly different ages ($t = 0.01$, $df = 9$, $p = 0.990$).

5.3.2 Comparison of durations of stages of parturition

The second stage of parturition was significantly longer for assisted cows and heifers, compared with unassisted animals ($F_{1,20} = 14.18$, $p = 0.001$). No difference was found between cows and heifers but there was a significant interaction between the two factors ($F_{1,20} = 5.59$, $p = 0.028$) that can be seen in Figure 5.01.

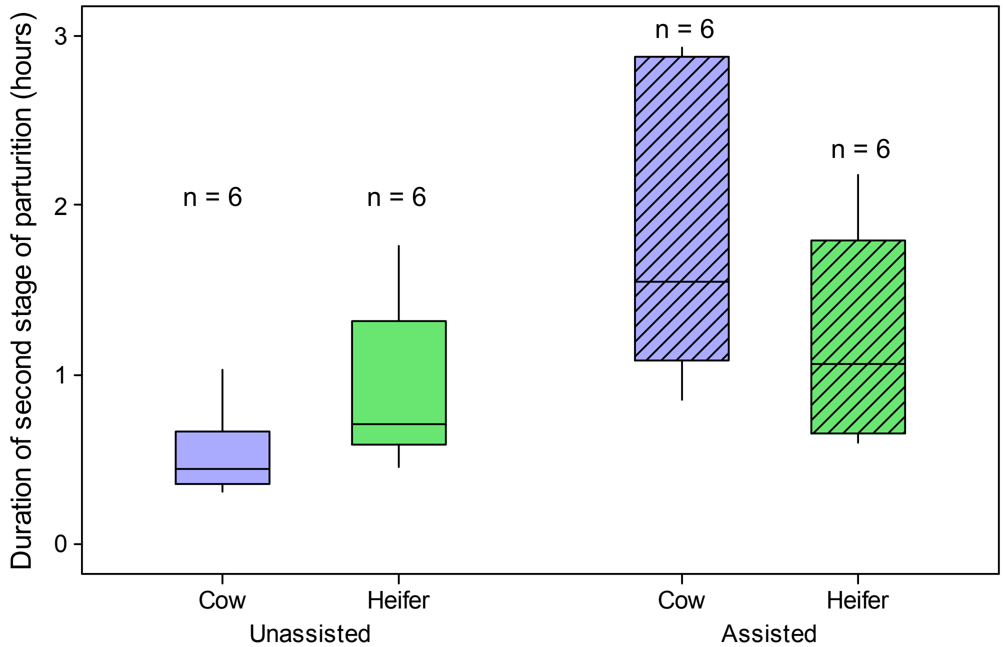

Figure 5.01
Box plot showing the durations of the second stage of parturition in cows and heifers that were unassisted or assisted at calving. There was a significant difference between assisted and unassisted individuals and a significant interaction between assistance and parity, as cows showed a more dramatic increase in duration for assisted calvings.

The durations of the third stage of parturition were not significantly different between parities ($F_{1,11}$ = 1.37, p = 0.267) or unassisted and assisted individuals ($F_{1,11}$ = 0.09, p = 0.768) and there was no significant interaction between these two factors.

5.3.3 Behavioural changes in the last 12 hours before normal and assisted calvings in cows and heifers

The first behaviour to be tested for differences within the last 12 hours before calving was the number of lying bouts (Figure 5.02). Significant differences were observed between calving and control observations (t = -3.856, df = 19, p = 0.001) but no other significant variation was found for the other factors or the interactions between them.

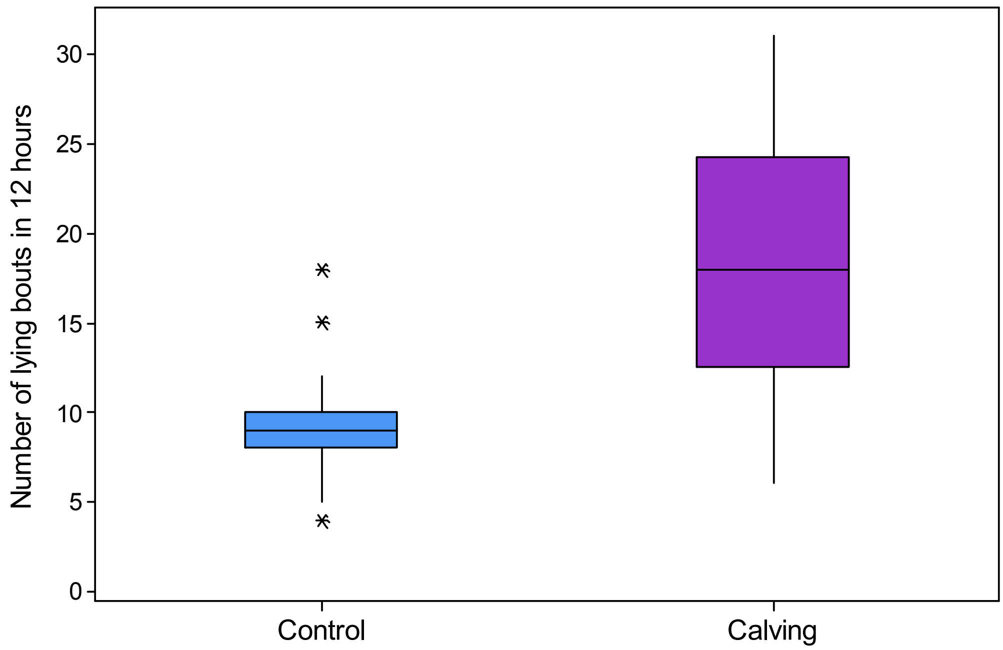

Figure 5.02
Box plots of the number of lying bouts during the 12-hour calving and control observations. Each group combines both parities and levels of assistance, as no significant variation was found between these factors.

No significant differences in lying duration were found between calving and control observations (t = 1.142, df = 19, p = 0.2675), or between parities (t = -0.579, df = 20, p = 0.5689) and assisted or unassisted dams (t = 1.167, df = 20, p = 0.2567). There were no significant interactions between any of these factors.

A significant three-way interaction was found for the number of walking bouts, between observation (calving or control) , parity and assistance (t = -2.463, df = 19, p = 0.0235). This is illustrated in Figure 5.03.

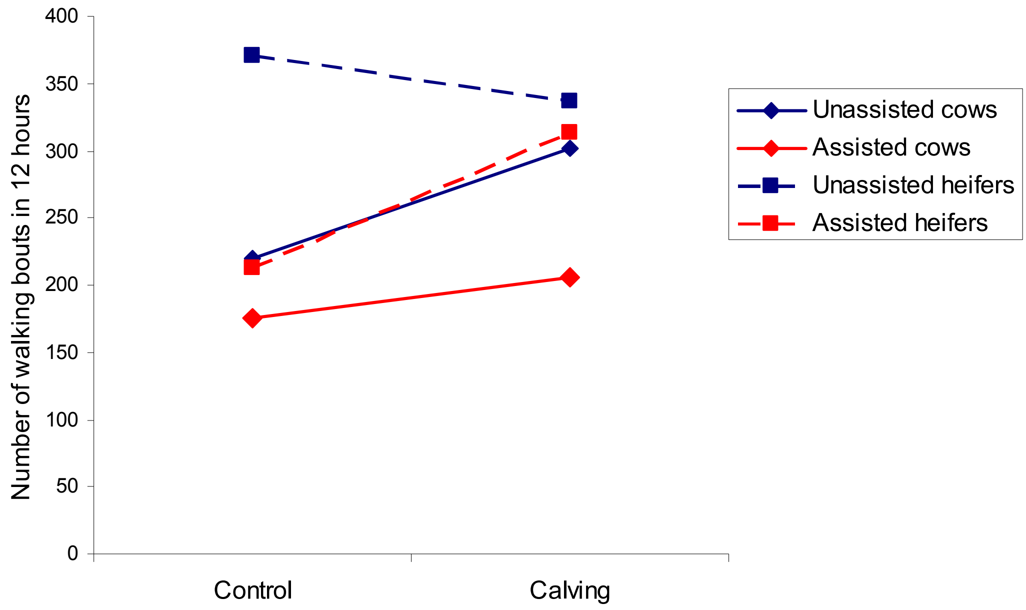

Figure 5.03
The number of walking bouts during calving and control observations varied between the four groups studied. There was a significant three-way interaction between observation, parity and assistance.

A significant difference in walking duration was observed between calving and control observations (t = -2.830, df = 19, $p < 0.001$) but no interactions or differences were found between parities and with assistance (Figure 5.04).

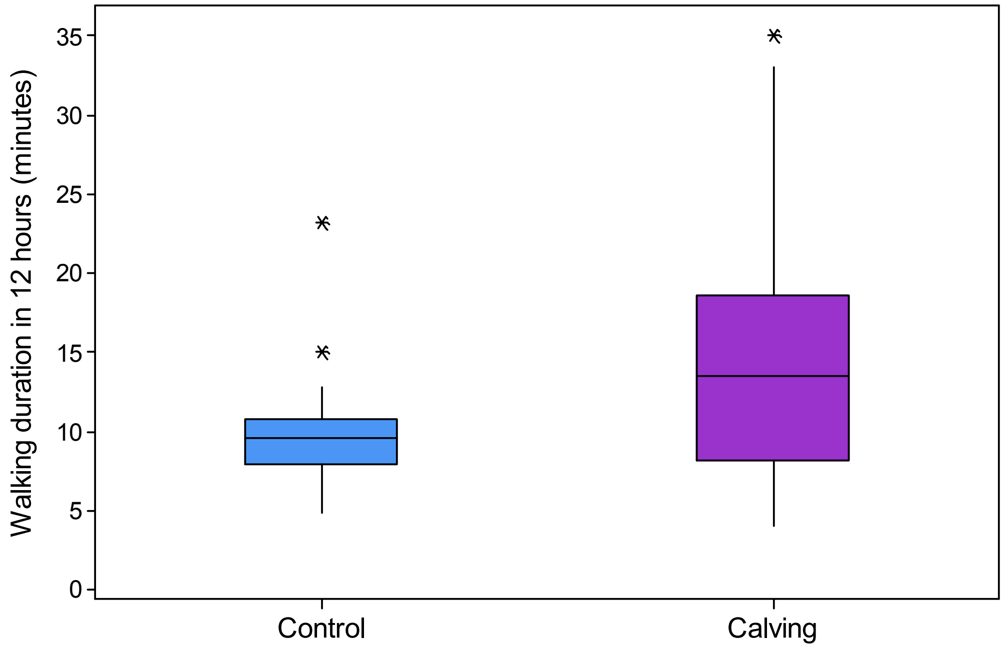

Figure 5.04
Box plots showing the durations spent walking during the 12-hour calving and control observations. The difference between these was significant but neither parity nor assistance had a significant effect on walking duration.

The frequency of tail raises showed a significant difference between the calving and control observations ($t = -4.005$, $df = 19$, $p < 0.001$). There were no significant interactions between factors or effects of parity or assistance (Figure 5.05).

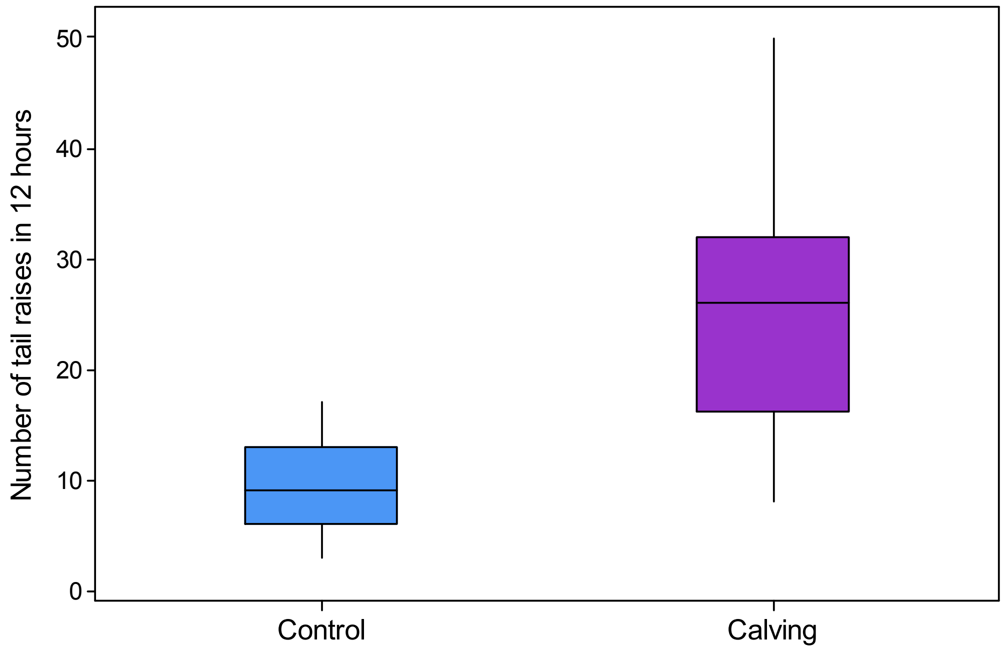

Figure 5.05
Box plots of the number of tail raises during the 12-hour calving and control observations. Each group combines both parities and levels of assistance, as no significant variation was found between these factors.

Tail raising duration was significantly longer during calving observations when compared with the controls ($t = -6.793$, $df = 19$, $p < 0.001$). This is shown in Figure 5.06. There was also a tendency towards longer tail raising durations during assisted than unassisted calving observations ($t = 1.750$, $df = 20$, $p = 0.095$) but this was not significant at the 95% level.

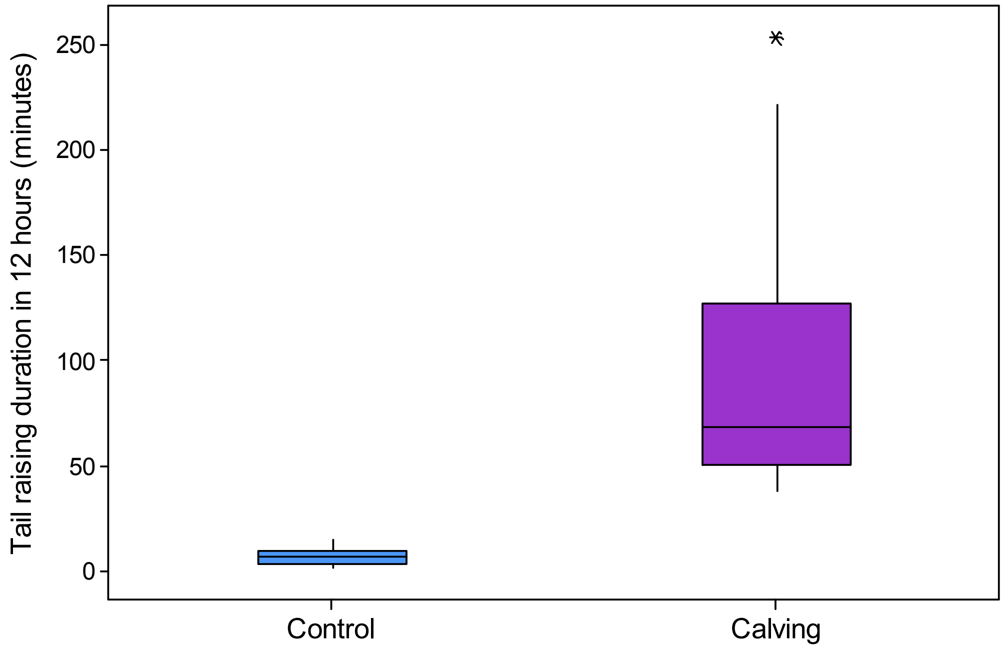

Figure 5.06
Boxplot showing the durations of tail raising during the 12-hour calving and control observations. The difference between these was significant but neither parity nor assistance had a significant effect on tail raising duration.

The duration of eating was significantly different between the 12-hour calving and control observations ($t = 4.456$, $df = 19$, $p < 0.001$). This is shown in Figure 5.07. The difference between cows and heifers was close to significance ($t = -2.015$, $df = 20$, $p = 0.058$) with heifers eating for less time (19.28 ± 10.3 minutes) than cows (26.18 ± 22.68 minutes) before calving. However, there was no significant effect of assistance ($t = -1.564$, $df = 20$, $p = 0.1336$) and no significant interactions between factors.

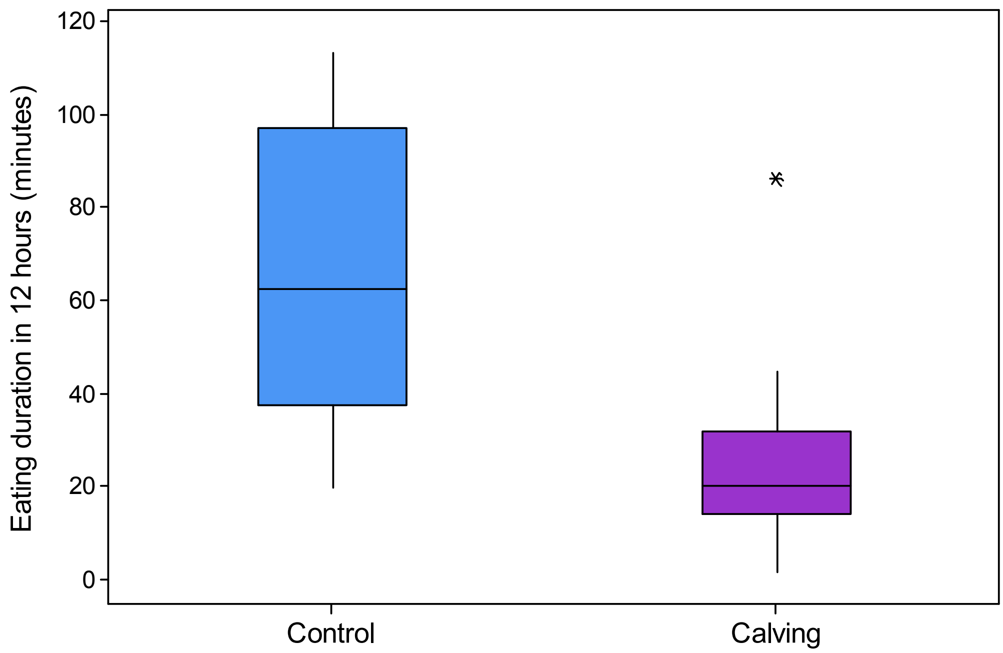

Figure 5.07
Box plots showing the durations spent eating during the 12-hour calving and control observations. The difference between these was significant but neither parity nor assistance had a significant effect on eating duration.

The duration of ground licking did not vary significantly in this analysis. However, there was a trend ($t = -1.901$, $df = 19$, $p = 0.073$) for more time to be spent licking the ground during calving observations, compared with control observations (Figure 5.08).

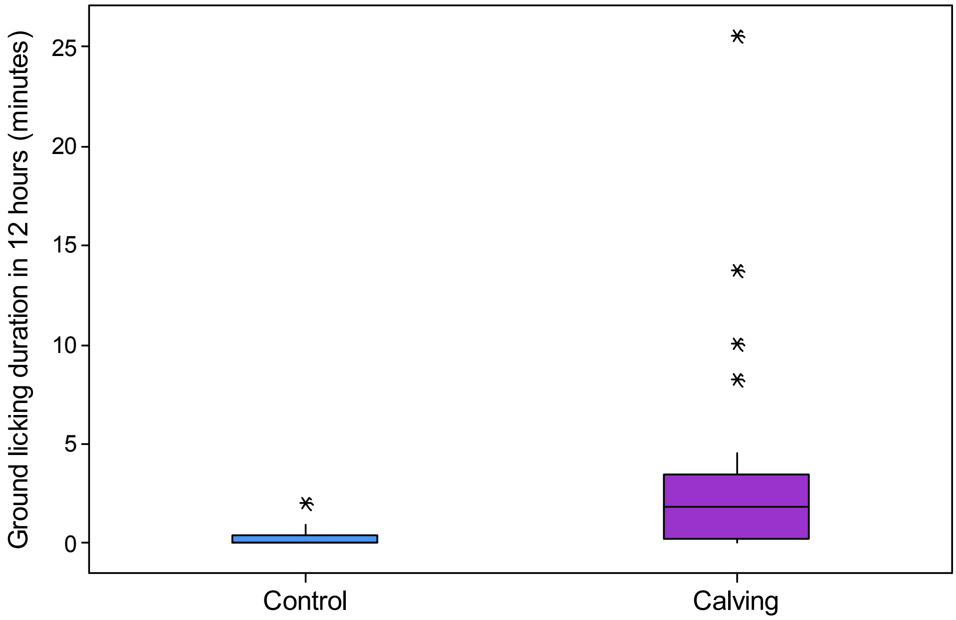

Figure 5.08
Box plots showing the durations spent licking the ground during the 12-hour calving and control observations. This difference was not significant but there was a trend for longer durations of ground licking during calving observations.

5.3.4 Time when behaviours change before normal and assisted calvings in cows and heifers

The next stage of the analysis was to study differences between the calving and control observations in shorter, two-hour periods to see when each behaviour changed in relation to calving and how this varied between groups.

The data for the number of lying bouts were not normally distributed, so were analysed using Friedman's tests. Unassisted cows showed significant changes in the difference between calving and control observations over the six two-hour periods before calving (Friedman's Q statistic = 14.72, df = 5, $p = 0.012$). The significant change appears to be due to the large increase during the final two-hour period before calving. Similar changes were observed in the unassisted group of heifers, with significant changes found in the difference between calving and control observations over the six two-hour periods before calving ($Q = 11.71$, df = 5, $p = 0.039$). Again, the significant difference appears due only to the large increase during the final two-hour period before calving. Data were missing for three cows from the assisted group which did not leave enough data to run the analysis. No difference was found between cows and heifers from the analysis of the 12-hour data, so the data for assisted cows and heifers were grouped and analysed together. Significant differences were found between the six two-hour periods for the combined assisted cows and heifers ($Q = 28.19$, df = 5, $p < 0.001$).

When all of the lying frequency data were plotted onto a single graph, the time when the changes before calving occur can be seen more clearly. None of the groups show a large increase in lying frequency between 4-12 hours before calving. Assisted cows and heifers appear to have an increased lying frequency from 2-4 hours before calving and the other groups only during the final two hours (Figure 5.09).

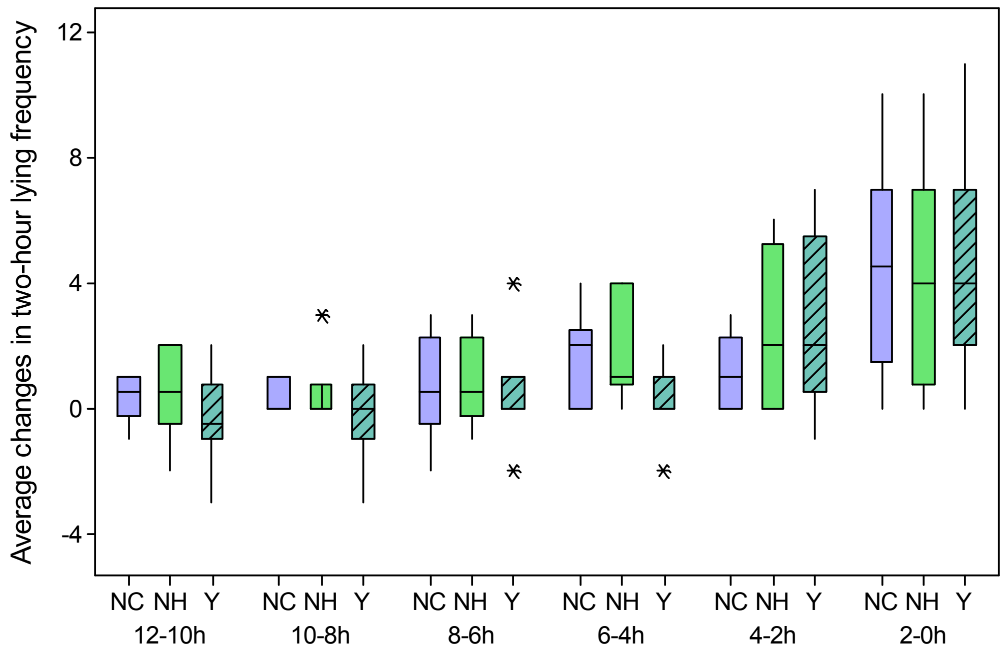

Figure 5.09
Box plots showing changes in the number of lying bouts between calving and control observations during two-hour periods before calving. The results of each of the groups are shown on this graph; unassisted cows (NC), unassisted heifers (NH) and assisted cows and heifers combined (Y).

The duration of lying was not different between the 12-hour periods, and this remained true for the unassisted cows which showed no changes in lying duration during the time before calving ($Q = 2.95$, $df = 5$, $p = 0.707$). As no difference between assisted cows and heifers was found in the 12-hour analysis, these were again combined to give an adequate sample size for analysis. Lying duration did not change significantly between the six two-hour periods for assisted cows and heifers ($Q = 1.95$, $df = 5$, $p = 0.856$). However, a significant result was found for the difference between calving and control observations for lying duration in unassisted heifers between the two-hour periods ($Q = 13.05$, $df = 5$, $p = 0.023$). This was due to a large increase in lying duration in the final two hours before calving (Figure 5.10).

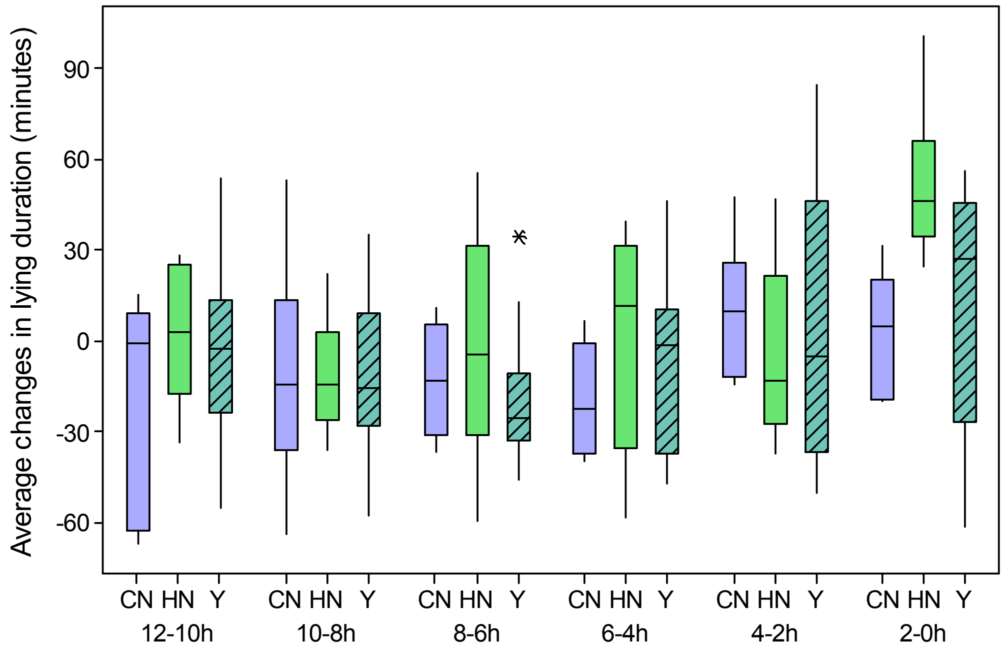

Figure 5.10
Box plots showing changes in lying durations between calving and control observations during two-hour intervals before calving. The results of each of the four are shown on this graph; unassisted cows (NC), unassisted heifers (NH) and assisted cows and heifers combined (Y).

Walking behaviour was analysed for both frequencies of bouts and durations during the two-hour periods. The first of these two variables to be tested was the change in the number of walking bouts between two-hour periods of the calving and control observations. These data were normally distributed for three of the groups so could be tested using a general linear model for each of these. The only group for which the data did not meet the assumptions of the GLM was the unassisted cows, so these values were analysed using a Friedman's test and no significant differences were found ($Q = 5.17$, $df = 5$, $p = 0.396$). As the data were normally distributed, the assisted cows and heifers could be tested separately for this behaviour. However, neither the assisted cows ($F_{5,20} = 0.52$, $p = 0.758$) nor assisted heifers ($F_{5,25} = 1.23$, $p = 0.323$) showed any significant variation in walking frequency before calving. The only group in which significant differences were observed were the unassisted heifers ($F_{5,25} = 3.31$, $p = 0.020$) which showed a decrease in the number of walking bouts during the final two hours before calving (Figure 5.11).

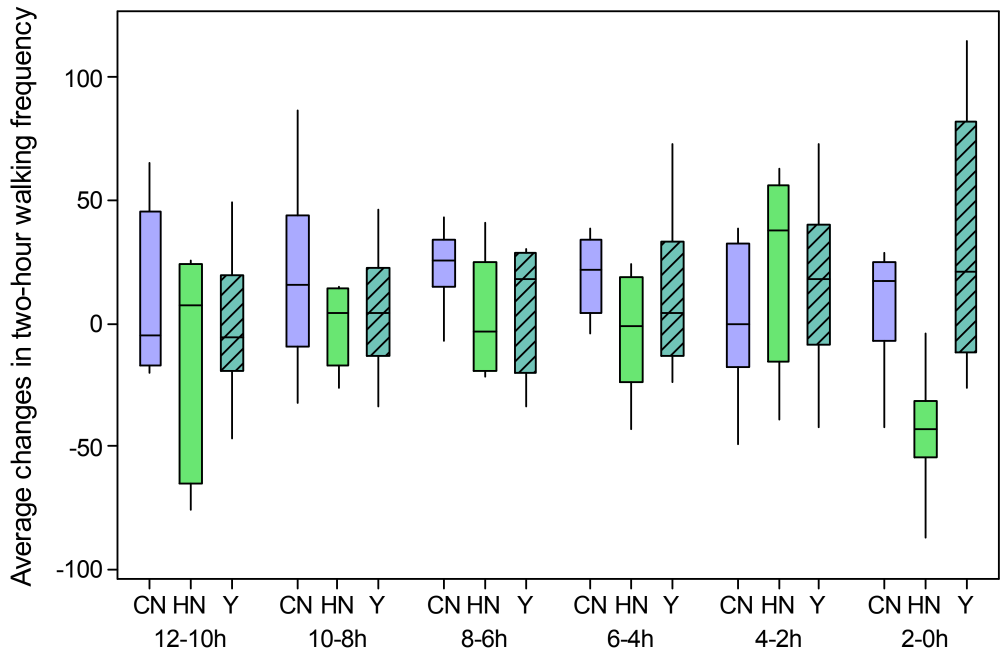

Figure 5.11
Box plots showing changes in the number of walking bouts between calving and control observations during two-hour intervals before calving. The results of each of the groups are shown on this graph; unassisted cows (NC), unassisted heifers (NH) and assisted cows and heifers combined (Y).

The results for the duration of each two-hour period spent walking were very similar to those found from the frequency data. No significant differences were found between periods for unassisted cows (Q = 4.86, df = 5, p = 0.434) or for the combined assisted cows and heifers (Q = 2.78, df = 5, p = 0.734). However, the unassisted heifers showed a significant drop in walking duration during the final two hours before calving (Q = 11.14, df = 5, p = 0.049). The data for all three groups are shown in Figure 5.12.

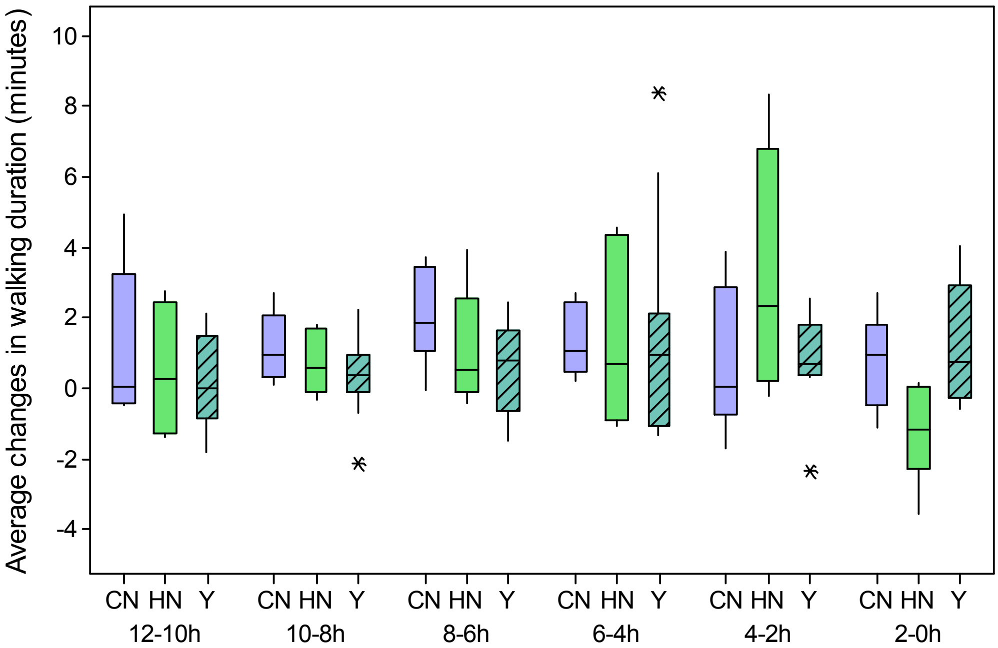

Figure 5.12
Box plots showing changes in walking durations between calving and control observations during two-hour intervals before calving. The results of each of the groups are shown on this graph; unassisted cows (NC), unassisted heifers (NH) and assisted cows and heifers combined (Y).

The number of tail raises during each two-hour period was expected to increase as calving approached. This was true for both unassisted cows ($Q = 11.35$, $df = 5$, $p = 0.045$) and heifers ($Q = 16.04$, $df = 5$, $p = 0.007$). The combined group of assisted cows and heifers also showed significant changes in tail raising frequency ($Q = 14.63$, $p = 0.012$). The group of unassisted heifers showed an earlier increase at 2-4 hours before calving than the unassisted cows and assisted group, which both peaked during the final two-hour period (Figure 5.13).

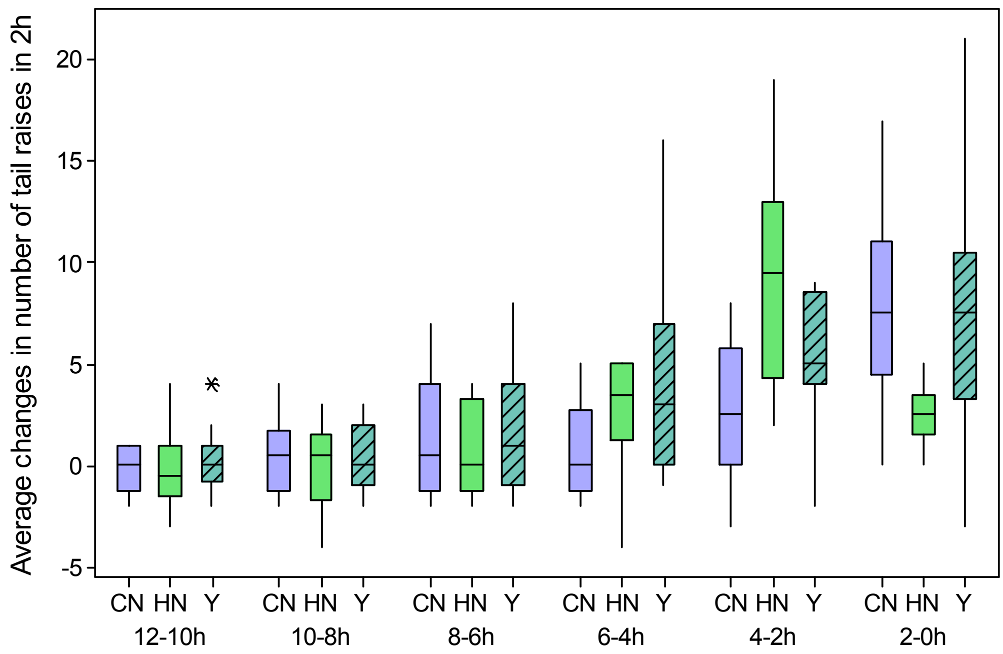

Figure 5.13
Box plots showing changes in the number of tail raises between calving and control observations during two-hour intervals before calving. The results of each of the groups are shown on this graph; unassisted cows (NC), unassisted heifers (NH) and assisted cows and heifers combined (Y).

The pattern of change was slightly different when tail raising was analysed in terms of duration. Again, both the unassisted cows (Q = 14.29, df = 5, p = 0.014) and unassisted heifers (Q = 23.62, df = 5, p < 0.001) showed significant changes associated with calving. The assisted cows and heifers also raised their tail for significantly longer at calving (Q = 29.33, df = 5, p < 0.001). However, all groups had their longest tail-raising durations in the final two hours before calving. The increase in duration was seen earliest in the assisted group, from 4-6 hours before calving, followed by the unassisted heifers, from 2-4 hours before. Unassisted cows only showed an increase in the duration of tail raising during the final two hours before calving (Figure 5.14).

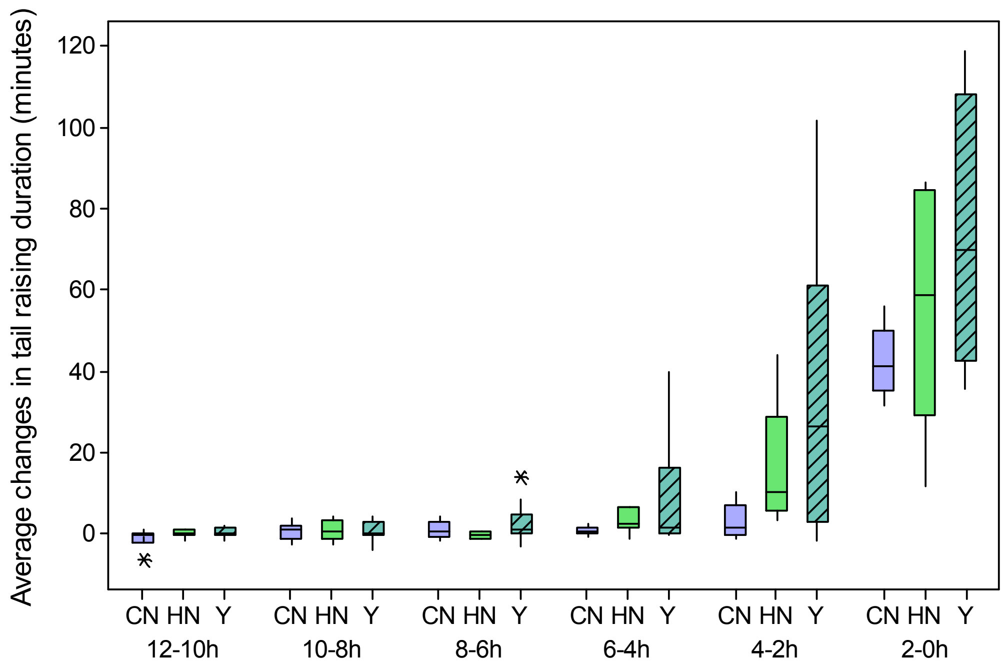

Figure 5.14
Box plots showing changes in the duration of tail raising between calving and control observations during two-hour intervals before calving. The results of each of the groups are shown on this graph; unassisted cows (NC), unassisted heifers (NH) and assisted cows and heifers combined (Y).

A decrease in eating duration was expected in the hours before calving but no differences were observed between two-hour periods. All of the results for unassisted cows (Q = 4.23, df = 5, p = 0.517), unassisted heifers (Q = 4.86, df = 5, p = 0.434) and the combined assisted cows and heifers (Q = 5.39, df = 5, p = 0.371) were not statistically significant.

The results for the duration of ground-licking emphasised how infrequently this behaviour was observed. Unassisted cows showed a slight increase in the final two hours before calving but this was not statistically significant (Q = 9.64, df = 5, p = 0.086). No change was observed in the group of unassisted heifers (Q = 2.24, df = 5, p = 0.815) but this behaviour increased significantly in the combined group of assisted cows and heifers (Q = 14.63, df = 5, p = 0.012). The only animals that spent any substantial duration licking the ground before calving were those that were given assistance (Figure 5.15).

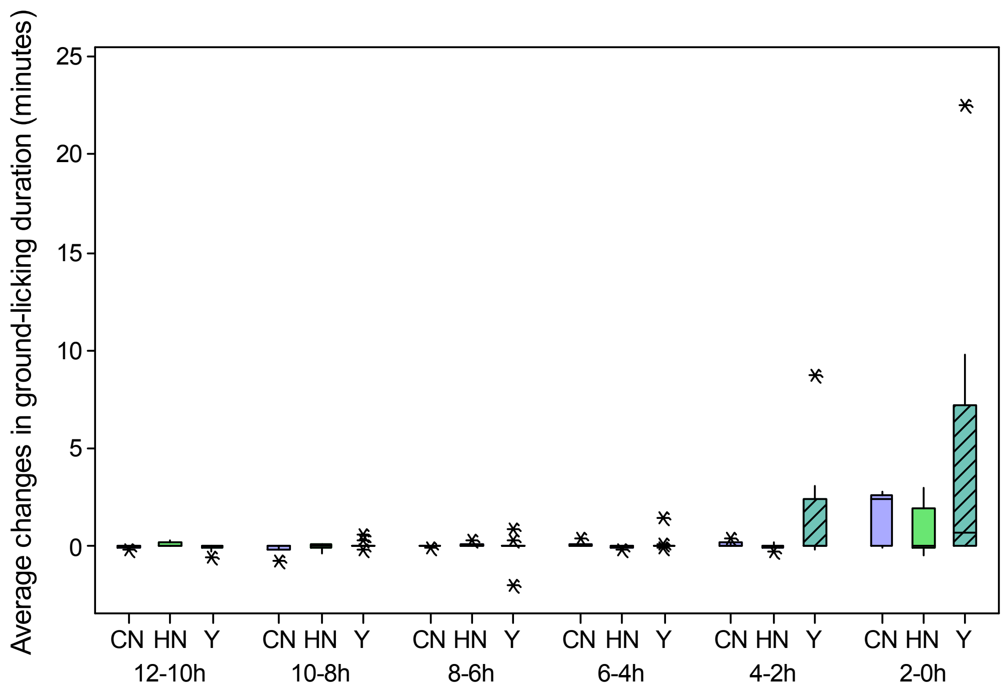

Figure 5.15
Box plots showing changes in the duration of ground licking between calving and control observations during two-hour intervals before calving. The results of each of the groups are shown on this graph; unassisted cows (NC), unassisted heifers (NH) and assisted cows and heifers combined (Y).

5.3.5 Comparison of latencies of events following calving

The times taken for dams to stand following the birth of their calf are summarised in Table 5.02. There were no differences in the latencies of these four groups to stand following calving ($H = 0.09$, $df = 3$, $p = 0.993$).

Table 5.02 Latency of dams to stand up after calving

	n	Minimum	Maximum	Median
Cows – unassisted	6	1 s	2.7 min	0.2 min
Cows – assisted	6	0 s	8.6 min	0.5 min
Heifers - unassisted	6	0 s	3.8 min	0.3 min
Heifers – assisted	6	0 s	7.0 min	1.2 min

The latencies before dams started licking their calves are summarised in Table 5.03.

Table 5.03 Latency of dams to start licking their calf following parturition

	n	Minimum	Maximum	Median
Cows – unassisted	6	0.2 min	2.9 min	0.3 min
Cows – assisted	6	0.5 min	2.0 min	1.3 min
Heifers - unassisted	6	0.3 min	3.8 min	0.5 min
Heifers – assisted	6	0.7 min	8.6 min	2.0 min

There were no differences in the latencies of these four groups to start licking their calves following calving ($H = 5.57$, $df = 3$, $p = 0.135$). However, there was a significant difference between assisted and unassisted individuals when parities were combined ($W = 115.5$, $p = 0.049$) (Figure 5.16).

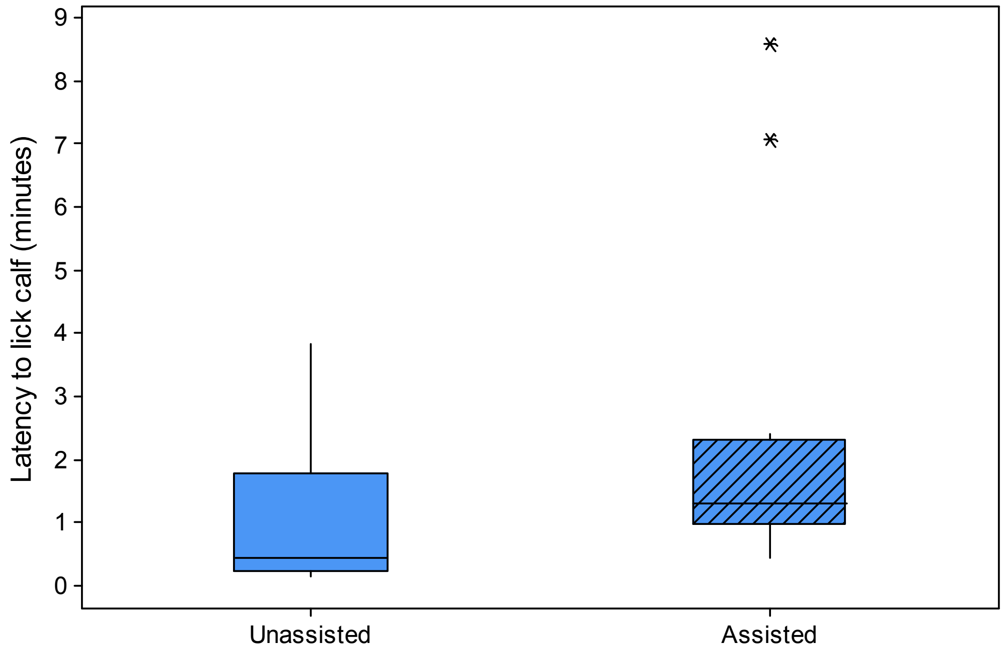

Figure 5.16
Box plots of the latencies of assisted and unassisted dams to start licking their calves are shown. Cows and heifers were combined, giving a total of 12 dams in each group.

There were no significant differences between groups in the time taken for calves to stand from when they were born (H = 1.61, df = 3, p = 0.657). Those from assisted births tended to take longer to stand but there was a lot of individual variation in the data (Table 5.04).

Table 5.04 Latency of calves to stand

	n	Minimum	Maximum	Median
Cows – unassisted	5	0.4 h	1.3 h	1.0 h
Cows – assisted	6	0.6 h	1.6 h	1.0 h
Heifers - unassisted	6	0.2 h	3.5 h	0.6 h
Heifers – assisted	5	0.6 h	1.3 h	0.9 h

The time taken for calves to suckle for the first time was extremely variable and in some cases may have been longer than six hours. No significant differences were found between the four groups (H = 2.25, df = 3, p = 0.523). The available data are summarised in Table 5.05 but the samples were small due to the large number of calves not suckling within the first six hours. However, the overlap between groups suggests that there are not likely to be any large differences.

Table 5.05 Latency of calves to suck for the first time (within the six hour observed)

	n	Minimum	Maximum	Median
Cows – unassisted	3	0.7 h	2.3 h	1.6 h
Cows – assisted	2	1.5 h	2.8 h	2.2 h
Heifers - unassisted	5	0.9 h	3.0 h	2.5 h
Heifers – assisted	2	2.0 h	4.0 h	3.0 h

5.4 Discussion

It was reported in Chapter 3 that there were fairly high numbers of assisted calvings at Langhill Farm, at 47.1% overall. This included all assistance, from minor pulls of calves that were already partly expelled, to major veterinary interventions. For the purpose of this investigation, to examine differences between calvings that were unassisted and presumed to be normal and those that needed some assistance, a definition of a difficult calving was needed. It was difficult to make this distinction from the video records and notes made by the stockmen alone because there may have been some cases when the cow was assisted prematurely and would have calved naturally, if given more time. There was some evidence from the farm records that would suggest that perhaps not all of the assisted cases required physical intervention at the time of calving. The fact that more calvings were assisted during the day, when the farm staff are around more often, compared with between the hours of 18:00 and 06:00, when they are observed less frequently, may indicate that when cows are observed to have started calving they are more likely to be assisted. There were also differences in the levels and frequency of assistance given by each worker on the farm. This could be due to differences in attitude towards cows (Hemsworth *et al.*, 2002; Waiblinger *et al.*, 2002) or in how they perceive pain or discomfort (Huxley and Whay, 2006).

However, there is also evidence from other literature that would suggest that some of the assistance observed was genuinely necessary and beneficial to the dam. Many papers have reported higher incidences of calving problems in heifers that often need human intervention (Lombard *et al.*, 2007; Bleul, 2008). In Chapter 3 evidence was presented that cows assisted one year are more likely to be assisted at calving again the following year, suggesting that certain individuals may be predisposed to calving problems.

The definition was straightforward for unassisted calvings, as these were the dams that calved without any human intervention and did not appear to have any problems doing so. The difficult calving category was selected to be those that were slightly further along the continuum from normal to extremely difficult, and classed as those that were assisted using a calving jack for at least one minute. This was done to exclude any cases where calves may have been pulled out relatively quickly and cows may have calved without any problems if given more time.

The duration of the second stage of parturition was calculated for all of the cows in this part of the study, as accurately as could be determined from the video recordings. This stage was longer in assisted individuals but there was an interaction with parity, such that the increase in duration with difficulty was much larger in cows than in heifers. For the unassisted calvings, this stage was longer in heifers (around 45 minutes) than in cows (shorter than 30 minutes) This agrees with the findings of Wehrend *et al.* (2005) who defined the second stage as the time from the appearance of the feet until complete expulsion of the calf. This lasted an average of 40.1 ± 1.5 minutes in heifers (n = 11), compared with 18 ± 2.1 minutes in cows (n = 70). Heifers also required more abdominal contractions until the head was expelled (93.3 ± 1.6) relative to multiparous cows (56.5 ± 1.7). Both cows and heifers had longer stage two durations in the assisted group, compared with those that calved naturally. However, this increase was larger in multiparous individuals. This may be due to the management decisions made on the farm. Dargatz *et al.* (2004) found in a study of beef cattle in the United States that cows were allowed to spend longer in labour before they were assisted than heifers. The duration of this stage of parturition can be used as an indicator of dystocia. This was done in one study, in which individuals were assisted if there was no progress in two hours after the water bag burst (Wehrend *et al.*, 2006). When compared with this duration, many of the cows and heifers in the present study may have had only mild cases of calving difficulty, with only few of them fitting this definition of dystocia.

The ideal situation would be to introduce a protocol for calving that could be followed and that decisions were made on the basis of timed events during parturition. In studies of maternal behaviour in sheep, ewes are allowed to give birth unaided as far as possible but a protocol is used to determine when a ewe will be assisted. Assistance was only given if the ewe failed to progress through the normal time frame of events. These were if no parts of the lamb were seen for 60 minutes after the appearance of fluids, or no obvious progress was made for 120 minutes after parts of the lamb were seen. If the presentation of the lamb was abnormal, this was corrected and the ewe allowed to continue delivery, but if no progress was made the lamb was delivered manually (Dwyer and Lawrence, 1998). This is similar to the protocol for Holstein cattle described by Johanson and Berger (2003). In this study, cows were left for two hours after the appearance of the calf's feet, and assistance given if the cow has not made progress during this two-hour waiting period. In another example, cows were given a vaginal examination if no progress in parturition was observed two hours after the rupture of the amniotic sac (Wehrend *et al.*, 2006). This would allow normal calvings to be completed naturally but still provide assistance to those dams requiring it. However, it may be difficult to achieve the balance of allowing calving to progress and allowing prolonged labour, which can be detrimental to both the dam (Noakes *et al.*, 2001) and her calf (Bellows *et al.*, 1987; Lombard *et al.*, 2007).

The third stage of parturition was not recorded for nine of the cows in the study, with at least one of these lasting longer than six hours. Those that were recorded all lay within the expected range of two to six hours (von Keyserlingk and Weary, 2007). The sample sizes were fairly small but no significant differences were found between groups. Another study found that this stage was completed within eight hours after calving in 95% of animals with no difference between heifers and cows in the duration of this stage (Wehrend *et al.*, 2005).

The number of lying bouts, also referred to as lying frequency, was significantly different between the 12-hour calving and control observations. This was in agreement with the results from the 24-hour observations in Chapter 4, with the mean during the 12-hour control observation being approximately half that of the 24-hour control. However, the 12-hour calving mean was not much lower than that of 24-hour recording, showing that the main change in this behaviour was captured in the final 12 hours. No differences were found between parities or between assisted and unassisted individuals in this variable when examining the 12-hour totals. When this behaviour was investigated in shorter, two-hour periods the same pattern of change was seen in unassisted cows, unassisted heifers and the combined group of assisted animals. All of these showed the greatest increase during the final two-hour period, with only small increases observed before this time. Another study found differences between the number of standing bouts (inverse of lying bouts) of cows with dystocia and normal calvings. Dystocia was defined as those requiring assistance from at least two experienced farm workers. Totals over the 18 hours before calving were compared and cows with calving problems had more standing bouts (Proudfoot *et al.*, 2008). It is possible that this difference is only apparent over a longer period of observation or that this difference in behaviour is only associated with more severe cases of calving difficulty.

Lying durations were not significantly different between the 12-hour calving and control observations. Differences had been found between the 24-hour totals, but these were not large. Neither parity nor assistance had an effect on the lying duration and there were no interactions between factors. The fact that the number of lying bouts increases while the total duration does not change suggests that the lying bouts were shorter before calving, which fits with the description of restless behaviour. When the lying durations were examined in two-hour periods, significant changes before calving were only observed in unassisted heifers. The obvious change here was a large increase in lying duration during the final two hours before calving, in this group and is likely to be associated with the longer labour and large number of contractions required by heifers to delivery their calves naturally, when compared with multiparous cows (Wehrend *et al.*, 2005).

Walking frequencies varied significantly between calving and control observations. When the 12-hour calving and control periods were compared between heifers and cows that calved with or without assistance, a significant three-way interaction was found. The values for unassisted cows were around half that seen in the 24-hour recordings detailed in Chapter 4, as expected. The assisted heifers showed very similar values to this but the other two groups were quite different. The assisted cows had a similar average control value but this did not increase much during the calving observation. The unassisted heifers were the most interesting group, as the control value was the highest seen, and the walking frequency decreased for the calving observation to an average which was close to that of the other groups. This cannot be explained by a change in lying duration, or any increases in other potentially related behaviours and makes it difficult to determine any conclusive results regarding the increases seen in the other groups. When the two-hour periods were examined for changes in walking frequency, the unassisted heifers were the only group in which differences were observed. The number of walking bouts decreased significantly during the last two-hour period before calving, which is likely to be related to the increase seen in lying duration.

Walking durations were significantly different between 12-hour calving and control recordings but there were no differences between parities or assisted and unassisted groups. These results agreed with the 24-hour results showing that no information was lost in the shorter recording duration. The calving and control averages for the 12-hour results were approximately half that seen in the 24-hour results. When this was examined in two-hour periods, the same results were found as for the walking frequencies. Only the unassisted heifers showed significant differences between the time periods before calving, with a large decrease in walking duration in the final two hours when more time was spent lying. These results suggest that the frequency and duration of walking during two-hour periods are not useful measures to use for the prediction of calving.

The results for the frequencies of tail raises were the same for the 12-hour as for the 24-hour observations. The frequencies during the 12-hour observations were approximately half that of the 24-hour results in both the calving and control observations. When the two-hour periods were analysed, the earliest increase in the number of tail raises was observed in unassisted heifers, between 2-4 hours before calving. Unassisted cows and the group of assisted cows and heifers only showed an increase during the final two hours. This can again be explained by the longer duration of labour in heifers and could indicate the beginning of the first stage of parturition, as tail raising is common during this stage (Phillips, 2002). Changes in behaviour were also expected to be observed earlier in assisted individuals compared with those calving without any intervention, as a sign of prolonged labour, but this was not seen. It may be the case that there are no differences in behaviour or that assistance was given before any differences in behaviour could be measured.

Tail raising duration was added as an improved measure of tail raising behaviour. This was significantly longer during the 12 hours before calving. When the two-hour periods were analysed, increases in duration were seen the earliest in the assisted group, from 4-6 hours before calving. The unassisted heifers had longer durations of tail raising from 2-4 hours onwards and the latest increase was seen in the group of unassisted cows only during the final two hours before calving. These differences between the groups were closer to the changes that were expected.

The duration of eating was significantly different during the 12 hours before calving compared with the control observation and heifers tended to eat less than cows. The durations of eating observed during the 12-hour control observations were approximately half that of the 24-hour observations in Chapter 4, where no significant difference was found between the daily durations before calving compared to the control. In the previous chapter, shorter eating durations were seen in the periods from 6-12 hours and 0-6 hours before calving. However, no differences were seen when durations during these final 12 hours were analysed in two-hour periods. Changes in eating behaviour appear to happen gradually and are better observed over longer time periods. Cows begin to eat less from a few weeks before calving, as the uterus and growing foetus take more space (Jordan *et al.*, 1973; Hulsen, 2006). Then cows tend to reduce their intake on the day of calving but this appears to remain consistently low during the final 12 hours, rather than decreasing throughout this period. Shorter eating durations were observed in cows with dystocia (defined as those requiring assistance from at least two experienced farm workers) compared to those with unassisted calvings in another study of behaviour during the 18 hours before calving (Proudfoot *et al.*, 2008). This longer period of observation may show clearer differences in eating behaviour or it may be that a reduction in feeding time is only seen in dams with more severe cases of dystocia.

Ground licking durations were not significantly different between calving and control observations in the 12-hour analysis. This was significant in the 24-hour analysis in Chapter 4, although the difference was only an average of 3 minutes longer at calving and was mainly seen in the last six hours before calving. When two-hour periods of time were analysed, only the assisted dams spent significantly longer licking the ground in the last two hours before calving. This could be because this was the largest group and the sample sizes were too small to find a significant difference in the unassisted cows or heifers. However, the results do not suggest that time spent licking the ground would be useful behaviour to record for the prediction of calving.

These results show that there are differences between cows and heifers in their pre-calving behaviour that should be taken into account when predicting the time of calving from behaviour. Heifers that calved without assistance spent more of the last two-hour period lying down compared to the unassisted cows. As longer was spent lying, less of this two-hour period was spent walking and the number of walking bouts was lower. This is likely to be normal calving behaviour as heifers take longer and more contractions to expel their calf, which agrees with the findings that the second stage of parturition was longer in these dams. Earlier changes were also seen in the tail raising behaviour of the unassisted heifers compared with the unassisted cows. Both the number of tail raises and duration of tail raising increased from 2-4 hours before calving in heifers and only in the last two-hour period for multiparous cows. This behaviour is associated with the first stage of calving, which begins earlier in heifers so these differences reflect that difference between parities.

Less variation was observed between the pre-calving behaviour of assisted and unassisted animals. However, assisted dams spent longer with their tail raised from 4-6 hours before calving, which is earlier than any of the unassisted dams. It is possible that the first stage of parturition began earlier in these individuals but it is not unusual for this stage to begin from six hours or longer before the calf is born (Ball and Peters, 2004). The other difference observed between the assisted and unassisted groups was that only assisted dams spent more time licking the ground in the final two hours before calving. Licking the birth fluids after the water bag bursts is normal parturient behaviour (Hafez and Hafez, 2000) so could not be considered as a warning sign of a potentially difficult calving.

Seven of the cows calved while standing but the rest were all lying at the time when the calf was expelled. All unassisted dams stood up within four minutes of calving but some of those that were assisted took longer than this. All of the cows started licking their calves very soon after they stood up, or were within reach in the case of the cow which took longest to stand. Most of these were within the expected range of up to seven minutes after birth (von Keyserlingk and Weary, 2007). The longest latency to stand after calving was seen in an assisted heifers but this was not significant. However, assisted individuals had longer latencies to start licking their calves compared with those that were unassisted. In a study by Houwing *et al.* (1990) two of 14 cows and five of 16 heifers were standing when they gave birth unassisted. Those that were recumbent and did not need assistance stood up sooner after calving (3.6 ± 3.6 min) than those that were assisted (37.3 ± 40.2 min). Cows stood up sooner than heifers, but more heifers required assistance and calves were placed in front of the dam after assistance which delayed standing. In the current study, calves were also moved within licking distance of the dam when the birth was assisted so this would also increase the latency to stand. However, all of the dams in this study stood up and started licking their calves within ten minutes after birth, which suggests that none of the assisted calvings were extreme cases.

The time taken for calves to stand for the first time varied greatly from just over 15 minutes to about 3 hours 30 minutes. The median latency was around an hour for most groups. Wesselink *et al.* (1999) found a tendency for calves born from heifers to take longer to stand than those born to cows but this was not reflected in the current study. The median latency of calves to stand was shorter for both assisted and unassisted heifers in comparison to cows but the data varied widely and this difference was not significant. There was also no difference in the time to stand between assisted and unassisted calves. The time taken for calves to suckle was also extremely variable. The shortest time before the first successful suckling was 1.5 h and the longest observed within the six hours studied was 4 h, with median latencies of 2-3 hours. However, the sample sizes were small as this behaviour was not easily observed from the video recordings.

In conclusion, the number of lying bouts and tail raises show the most consistent changes before calving, in agreement with the results of Chapter 4. The measurement of the duration of tail raises appears to be an improvement to using frequencies alone, as changes were observed earlier using this measure of behaviour. However, the durations of eating and ground licking did not change in relation to calving over these shorter periods of observation.

Important differences were found between the behaviour of cows and heifers in their pre-calving behaviour. Changes in behaviour can be observed earlier in heifers because the stages of parturition tend to take longer in these younger dams. This may be one of the reasons why heifers are given assistance more often than cows but requires more research to define the optimum assistance protocol for different parities.

Only small differences in pre-calving behaviour were found between assisted and unassisted calvings. The durations of the second stage of parturition were longer in assisted dams but this stage did not continue for longer than two hours for many individuals. This suggests that some of these may have calved without assistance if given more time. The latencies of events after calving do not suggest that any of the cases of calving difficulty were extremely severe, which might explain why no differences were seen in the behaviour of these dams during the final hours before calving.

Chapter 6: Classification of behaviour using accelerometers

6.1 Introduction

6.1.1 Accelerometers

Accelerometers have frequently been used to measure movements related to the behaviour of a wide range of animals. These electromechanical devices measure static forces such as gravity and dynamic forces from movement or vibration, and can be used to classify behavioural states in various species.

There are several types of accelerometer but those used in this study were piezoelectric accelerometers. These work using piezoelectric crystals that produce a charge output when they are compressed, flexed or subjected to shear forces. The crystal is attached to the case of the accelerometer and a mass attached to the crystal. When this is subjected to vibration, the mass will stay in place due to inertia and cause compression or stretching of the crystal and generate a charge. The charge generated is proportional to the acceleration (Sensotec Sensors, 2009).

Acceleration is the time rate of change, of the time rate of change of distance, measured in metres per second squared (m/s^2). The units of output recorded by accelerometers are usually expressed as the g-force. This is the acceleration relative to free-fall and 1g is equal to the force of gravity, which is around 9.8 m/s^2. The output of a sensor with the base connector pointing up is +1g, down is -1g and a horizontal sensor will give an output of zero (Texas Instruments, 2009). Tri-axial accelerometers incorporate three piezoelectric sensors mounted to record three axes of movement in different directions.

6.1.2 Sampling frequencies and data quality

In the previous studies described in Chapter 1, the sampling frequencies from accelerometers ranged from 1-100 cycles per second or hertz (Hz). The lowest frequency was used to study porpoising behaviour in Adelie penguins (Yoda *et al.*, 1999) and the highest for spectral analysis of the behaviour of cows and horses (Schiebe and Gromann, 2006). The rest of the studies fell within this range and the sampling frequency depended on the study species and methods of analysis used. It is important to select a suitable sampling frequency that will provide a high enough resolution to capture behavioural events while remaining within a manageable and practical limit for analysis. The importance of precise alignment between accelerometers and the behaviour being measured becomes increasingly important as sampling frequency increases. When data are synchronised manually, differences of up to a second are expected. This would have a minimal effect on data recorded once a second but the impact will be greater at higher sampling frequencies.

6.1.3 Studying behaviour using accelerometers

The capability of devices containing accelerometers was described in Chapter 1. In terms of measuring animal behaviour, new methods are still being developed and it is likely that the limit of what is possible with this technology has not yet been reached. However, some studies have achieved interesting results using fairly basic methods. Yamada and Tokuriki (2000) attached accelerometers to dogs that recorded movements above three threshold values. None of the threshold values were reached when the dogs were lying, so this could be used as a way to measure lying behaviour. Another way of studying the relationship between accelerometer data and behaviour is to compare traces of accelerometer data against known patterns of behaviour. Tsuda *et al.* (2006) used visualisations of accelerometer traces from salmon during known behaviours to investigate the movements involved and help guide their numerical analysis.

6.1.4 Research aims

The central aim of this chapter was to investigate if features in three-axis accelerometer data can be identified that correspond to specific behaviours.

This was broken down into a number of smaller aims that could be tested and developed using the data collected.

1. To see what effect down-sampling accelerometer data has on the ability to distinguish different behavioural states visually and determine the most appropriate sampling frequency for studying the behaviour of cows.

2. To assess the quality of data collected and the reliability of collars containing tri-axial accelerometers in terms of how many stored files contained data suitable for analysis.

3. To visualise changes in accelerometer output that appear to correspond to changes in behaviour.

4. To summarise differences in the accelerometer output related to different behavioural states and use these to classify the data.

5. To test accuracy of behavioural classification from accelerometer outputs and how this is affected by differences between individuals

6.2 Methods

2.4.3 Basic collar design

Selected cows were fitted with collars containing tri-axial accelerometers during the time before calving. The collars were produced by BlueSky Telemetry and calibrated prior to delivery (BlueSky Telemetry, 2009). The accelerometers recorded a range of ± 2g at a frequency of 50 Hz and data were recorded onto a four gigabyte SD card which was removed to be read. The battery life from four AA batteries was approximately two days and the weight of the collar, including batteries, was 500-600 grams. The electronic components and batteries were contained within a solid plastic box attached to the collar that hung below the neck of the cow (Figure 6.01).

Figure 6.01
The collars used in the study were secured around the cow's neck with a buckle, suspending the hard case containing the accelerometers below the neck. The weight of the electronic components and batteries prevented excessive rotation of the collar.

The x-axis was strongly associated with forward and backward horizontal movements. The y-axis was strongly associated with sideways horizontal movements, and the z-axis was strongly associated with movements in the vertical dimension (Figure 6.02).

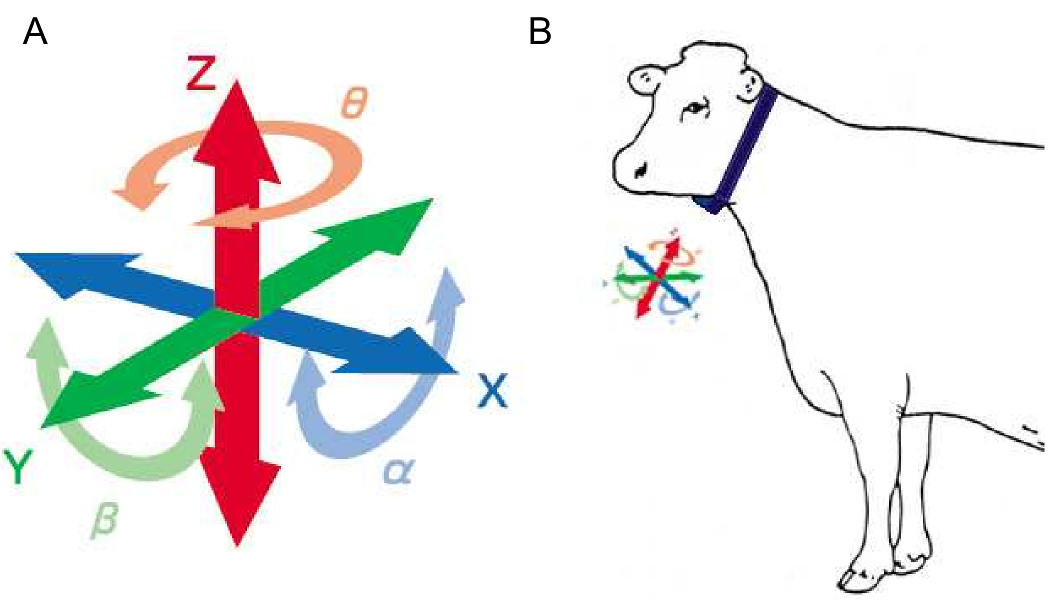

Figure 6.02
A. The three axes of movements detected by the accelerometers, when the device is positioned upright on a flat surface. The x-axis corresponds to one horizontal dimension, the y-axis corresponds to the second horizontal dimension and the z-axis corresponds to the vertical dimension.
B. The position of the collar on the cow and how the axes are orientated in relation to the cow's body.

2.4.4 Selection of focal animals

The cows studied in Chapter 4 for the analysis of normal behaviour before calving were used for this part of the study. These cows were chosen on the basis that they were fitted with collars before they calved and the data collected matched with the behavioural data from the behavioural analysis.

2.4.5 Synchronisation of collars with video recordings

Radio clocks that automatically updated to GMT were used to record the time when collars were started, put on and taken off cows. Collars were always started either exactly on the minute or on the 30-second mark. This was the best available method of synchronisation but some human error was possible and some of the data collected were not perfectly aligned.

Behavioural data from video recordings were visualised as shown in Chapter 4 (Figure 4.01) and this was used for comparison against the accelerometer outputs. The time on the video recordings was also synchronised with the radio clock, allowing data recorded onto the collar to be aligned with the cows' behaviour. Behavioural states associated with a characteristic change in accelerometer output were identified by visualising these two sets of data together.

2.4.6 Down-sampling, artefacts and visualisation of accelerometer data

The raw data from the tri-axial accelerometers were recorded at a frequency of 50 Hz. This sampling rate is extremely high, considering that cows do not normally change their behaviour more than once in a second. A much lower sampling frequency was considered to be adequate for the type of analysis conducted in the current study, and perhaps even more useful. The smaller files also made it easier to work with longer durations of recordings at any one time. For these reasons, the data were down-sampled from 50 Hz to 10 Hz, 5 Hz and 1 Hz. Visualisations were made at all four sampling frequencies to determine if any useful information appeared to be lost between the highest and lowest sampling rates.

The accelerometer data were saved as comma separated value (CSV) files, with the data from the x, y and z axes stored in the first three columns. These could be opened using The Observer XT software (Noldus Information Technology bv, 2007). Using this software, the start times of the collar data were used to align these files with the behavioural data. These could then be visualised together to show how changes in behavioural states relate to the output recorded by the accelerometers. This was the first stage of the analysis and visualisations were made from more than one cow to see if the same patterns could be observed or if there were distinctive variations in the accelerometer output from different individuals.

The initial visualisation showed that artefacts were present in many of the files, of very high values (253-254g) outside the range of ± 2g recorded by the accelerometers. These were especially frequent in the z axis data. There were only a small number of these high values in the x and y axes for many of the files. In cases where there were fewer than 10 per file, these artefacts were edited out and replaced by the previous value within the normal range.

Files with acceptable accelerometer traces (all values within ± 2g) were then visualised to inspect their alignment with the behavioural observations.

2.4.7 Trends in accelerometer data relating to behavioural states

When a suitable behaviour was identified for analysis, e.g. where there were visually distinctive simultaneous changes in behaviour and accelerometer recordings, accelerometer output from within-bout intervals were compared with between-bout intervals to identify any distinct differences between them in any of the three axes. The medians were compared to look for features that could be used to identify behavioural states in one individual.

Threshold values between states were estimated by calculating medians for every 10 seconds of data and comparing these between behavioural states. These thresholds were then used as the basis for simple rules to discriminate between states using the accelerometer data.

Accelerometer data from different cows were used to test each rule separately. Medians were calculated from each ten seconds of data and classified using the rules. The states inferred from the accelerometer data were then compared with the behaviours from video observations to determine the accuracy of the analysis.

2.4.8 Testing accuracy of behavioural classification

The sensitivity and specificity of each rule was calculated as a measure of success. This required each ten-second epoch to be scored as one of four terms;

1. True Positive (TP) = correct identification of target behaviour
   (Predicted = 1: actual = 1)
2. True Negative (TN) = correct identification of alternative behaviour
   (Predicted = 0: actual = 0)
3. False Positive (FP) = incorrectly classed as target behaviour
   (Predicted = 1: actual = 0)
4. False Negative (FN) = incorrectly classed as alternative behaviour
   (Predicted = 0: actual = 1)

Sensitivity is calculated as; TP/(TP+FN), and specificity as; TN/(TN+FP).

6.3 Results

6.3.1 Data collection

Recordings were made of the cows studied in Chapter 4. Accelerometer data were recorded matching at least part of the 24-hour behavioural observations before calving for 19 of these 20 cows, and matching the 24-hour control observations for 17 of the same group of 20 cows. One calving file and three control files were missing because the cows were not fitted with collars at these times. Some of the recordings did not last the duration of the behavioural observations and there were also gaps in some of the behavioural observations. The gaps in behavioural data were due to problems with videos or when cows were moved outside the area covered by the video cameras.

The duration of matching data for behavioural and accelerometer recordings for each individual varied from 17 hours to the maximum possible of 48 hours, and the total duration of matching data without gaps in either the accelerometer or behavioural recordings was 750 hours. For any gaps in the data, the whole hour that included the gap was excluded from the analysis. These are summarised in Appendix C.

6.3.2 Visual comparison of four sampling frequencies

The data were originally sampled at a frequency of 50 Hz. The control observation from cow number 4 was used to visually compare the original recordings with lower sampling frequencies (1, 5 and 10 Hz). The three axes were displayed separately for ease of comparison, with the x-axis displayed first (Figure 6.03).

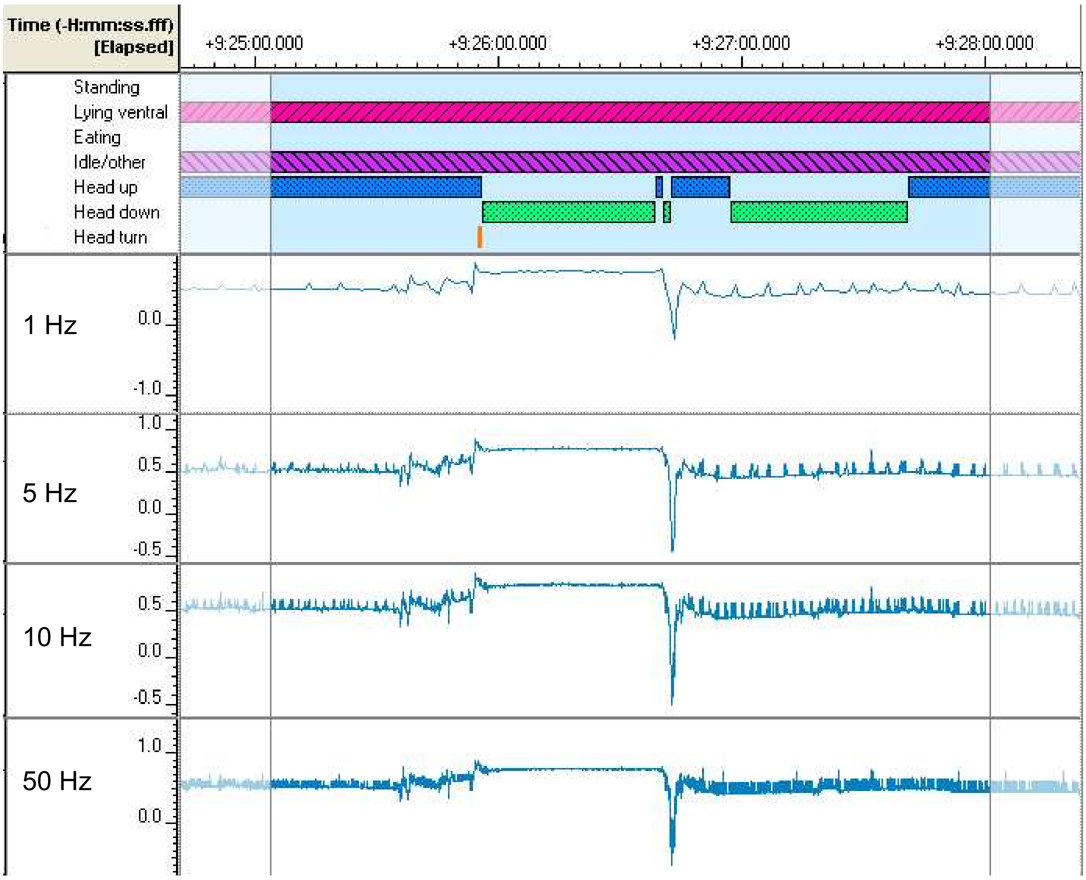

Figure 6.03
Output from the Observer XT, showing the main behavioural states of cow 4 during the control observation at the top. The lower part shows data taken from the accelerometer recordings of the x-axis in blue. The accelerometer was originally sampled at 50 Hz and was also down-sampled to 1, 5, 10 Hz.

The y-axis was also visualised at a range of sampling frequencies (Figure 6.04).

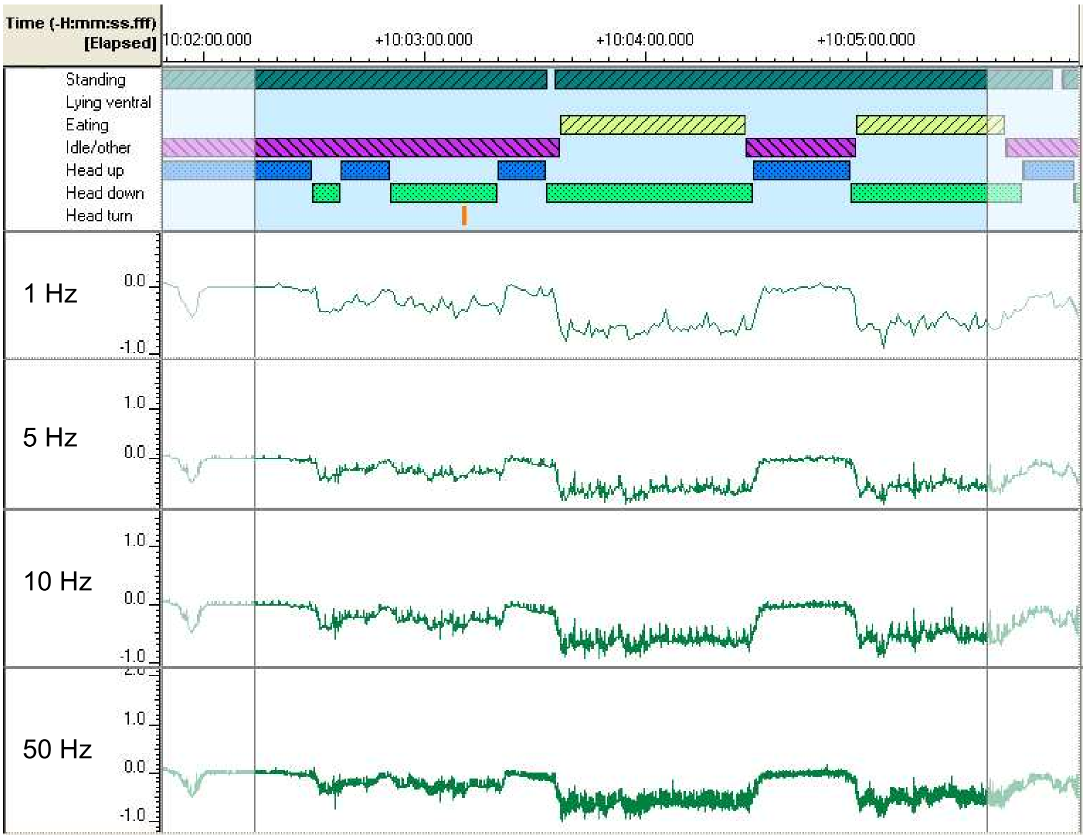

Figure 6.04
Output from the Observer XT, showing the main behavioural states of cow 4 during the control observation at the top. The lower part shows data taken from the accelerometer recordings of the y-axis in green. The accelerometer was originally sampled at 50 Hz and was also down-sampled to 1, 5, 10 Hz.

Finally, the z-axis was shown at the four sampling frequencies (Figure 6.05).

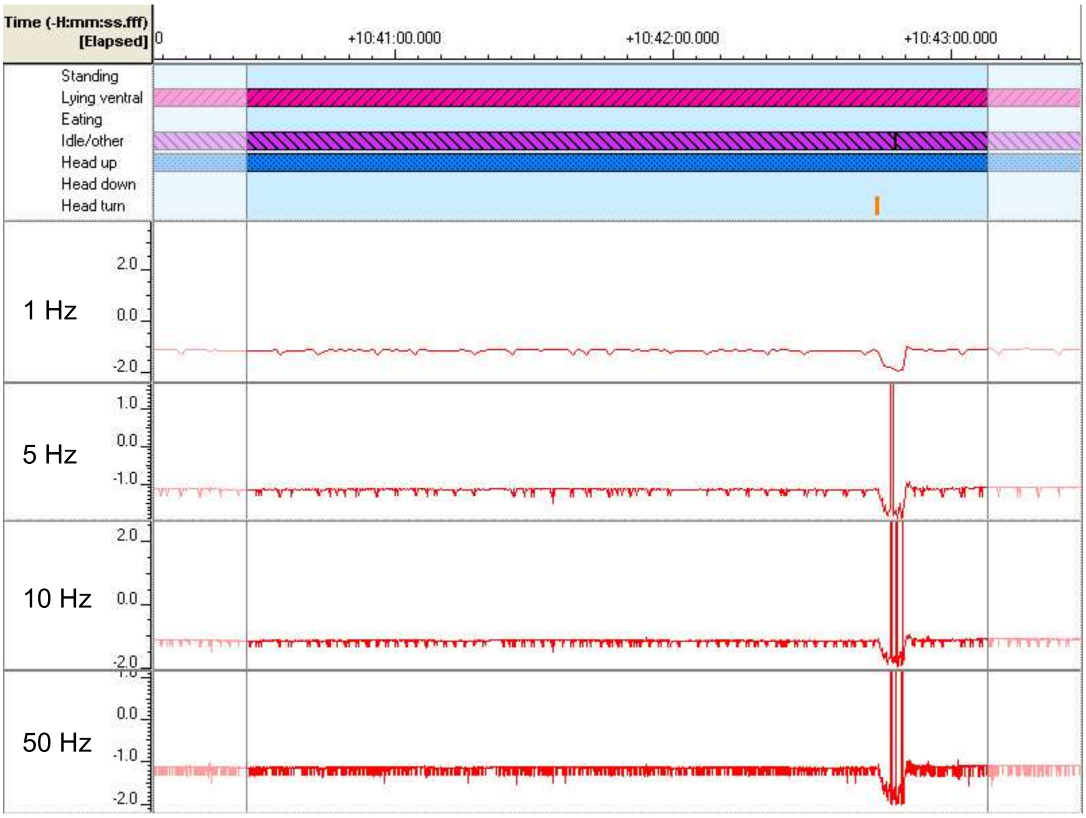

Figure 6.05
Output from the Observer XT, showing the main behavioural states of cow 4 during the control observation at the top. The lower part shows data taken from the accelerometer recordings of the z-axis in red. The accelerometer was originally sampled at 50 Hz and was also down-sampled to 1, 5, 10 Hz.

From these visual inspections of the data down-sampled to different frequencies, the 1 Hz frequency appeared to be the most appropriate for the behaviours of interest. Even short events, such as a head turn, were shown clearly by the 1 Hz data, so these were used for further analysis.

6.3.3 Assessing the quality of data recorded

In Figure 6.05, artefacts can be seen in the z-axis data sampled at 5-50 Hz. These values were of a different order of magnitude from the normal range of the data and outside the limit of accelerometer measurement, so would have a large impact on the results. Only 10 files were free of these artefacts in all three axes, with the most problems appearing in the z-axis. These were edited out of files that had fewer than 10 of these higher values. Table 6.01 provides a summary of the files in which artefacts were found and those that were edited and used for further analyses.

Table 6.01 Summary of the artefacts found in the x, y and z axes of each file, including details of those that were fixed and those that were excluded from any further analysis. (* denotes missing data files)

	Calving files			Control files		
Cow ID	x	y	z	x	y	z
4	Rejected	Accepted	Rejected	Edited	Accepted	Rejected
13	Edited	Edited	Rejected	Rejected	Edited	Rejected
30	Edited	Edited	Rejected	Edited	Accepted	Rejected
47	Edited	Edited	Rejected	Edited	Edited	Rejected
51	Edited	Accepted	Rejected	Edited	Edited	Rejected
53	Edited	Accepted	Rejected	Edited	Edited	Rejected
80	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted
85	Edited	Edited	Rejected	Rejected	Rejected	Rejected
101	Rejected	Rejected	Rejected	Edited	Edited	Rejected
122	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected
130	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted
136	Accepted	Accepted	Accepted	*	*	*
156	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted
187	Edited	Edited	Rejected	*	*	*
189	Edited	Edited	Rejected	Rejected	Rejected	Rejected
191	Accepted	Accepted	Accepted	*	*	*
205	Rejected	Accepted	Rejected	Edited	Accepted	Rejected
207	*	*	*	Accepted	Accepted	Accepted
216	Accepted	Accepted	Rejected	Accepted	Accepted	Accepted
248	Edited	Edited	Rejected	Edited	Rejected	Rejected

Most of the files had a lot of artefacts in the z-axis but only a few in the other two axes. After editing, there were 28 files with useable x-axis data (77.8%), 30 files with y-axis data (83.3%) and only 10 files with z-axis data (27.8%) within the range of

±2g. Figure 6.06 shows the difference seen in the data before and after editing a small number of values.

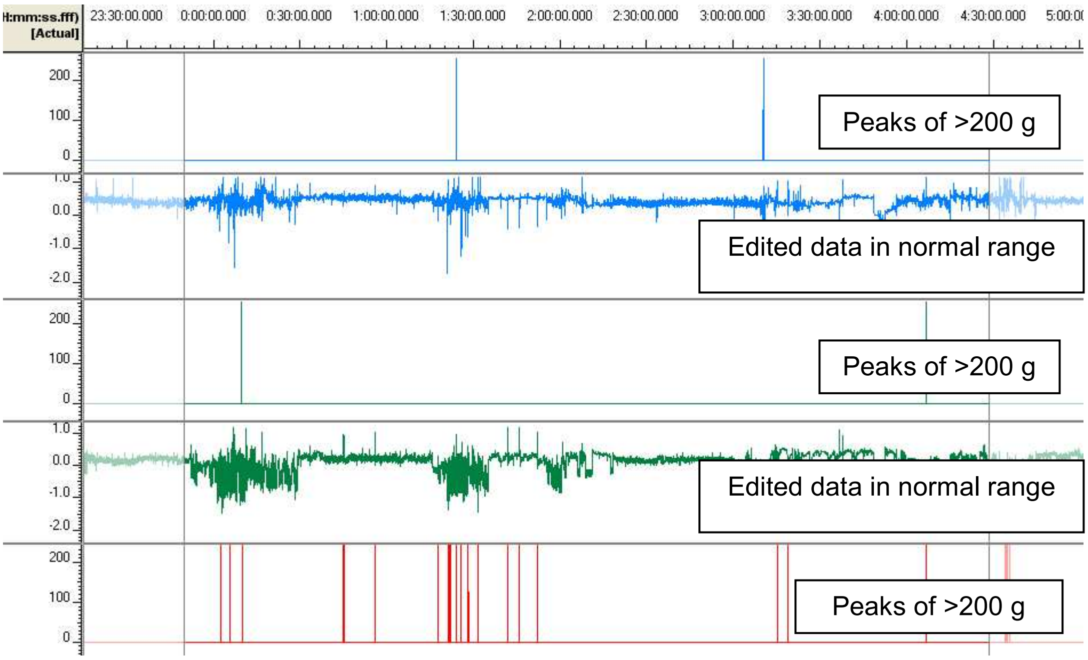

Figure 6.06
Accelerometer data matching the calving observation of cow 47. The top two blue traces show the x-axis data, before and after editing. The unedited line at the top has a scale going up to over 200, whereas the edited line has a maximum value around 1.0. The same can be seen in the green y-axis data. The z-axis is shown at the bottom, in red, but in this case there were too many artefacts to edit out and the data was rejected.

6.3.4 Visual comparisons of behavioural and accelerometer data

From the alignment of accelerometer and behavioural data, eating appeared to be an appropriate behaviour to analyse. The most obvious correspondence was evident in the x and y axes. The x-axis shows a slight increase in amplitude during eating and y-axis values appear to decrease during eating (Figure 6.07).

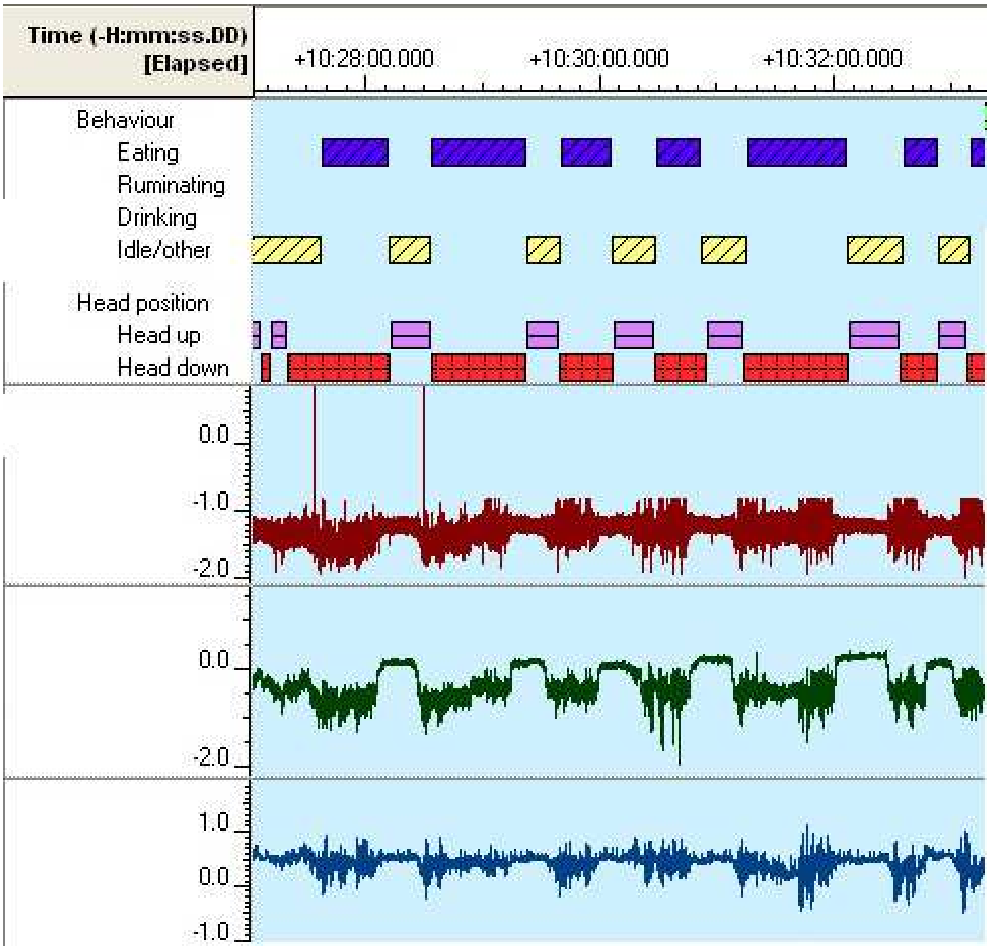

Figure 6.07
Output from the Observer XT showing behavioural states of cow 101, aligned with three axes of accelerometer data. Red = z, green = y and blue = x. A clear change in the y axis can be observed when the cow is eating.

The differences in y-axis data observed during eating appear to be closely related to the head position. Upwards and downwards movements of the head can be clearly seen from all three axes of the accelerometer data (Figure 6.08).

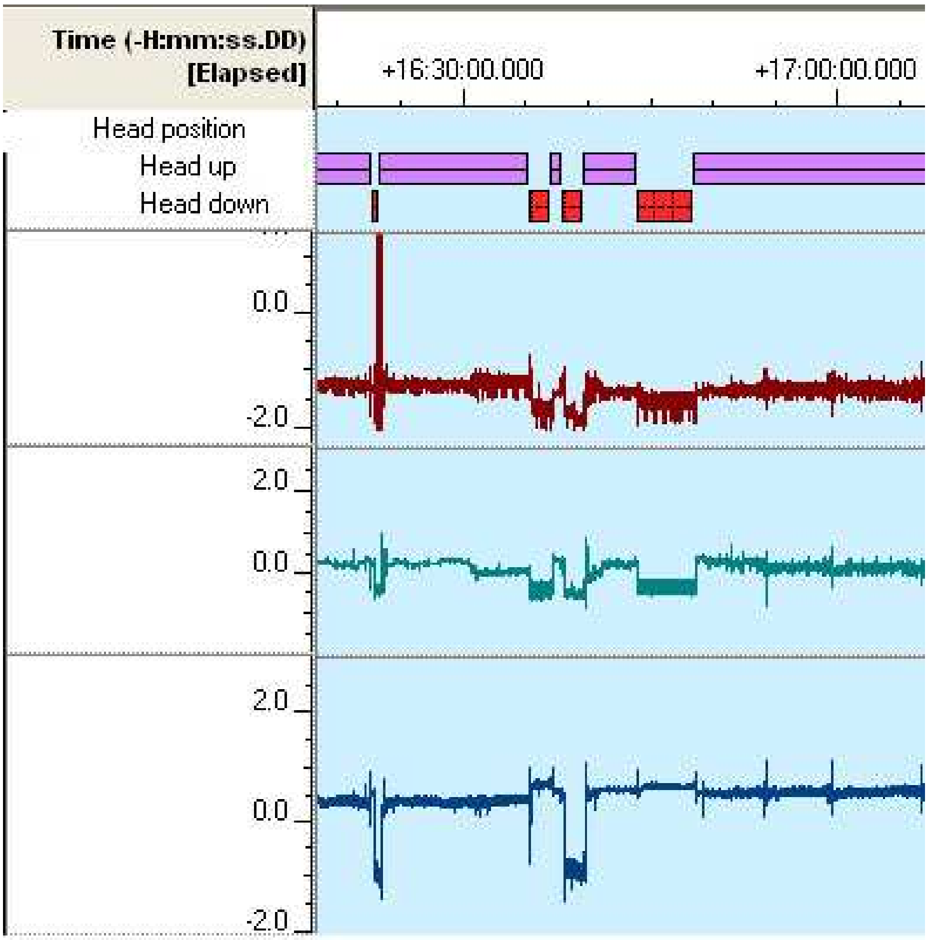

Figure 6.08
Output from the Observer XT showing behavioural states of cow 47, aligned with three axes of accelerometer data. Red = z, green = y and blue = x. All three axes show changes associated with head movements.

Lying and standing also show an apparent change with the accelerometer data (Figure 6.09). In this case, the amplitude of all three axes appears greater when the cow is standing than when it is lying.

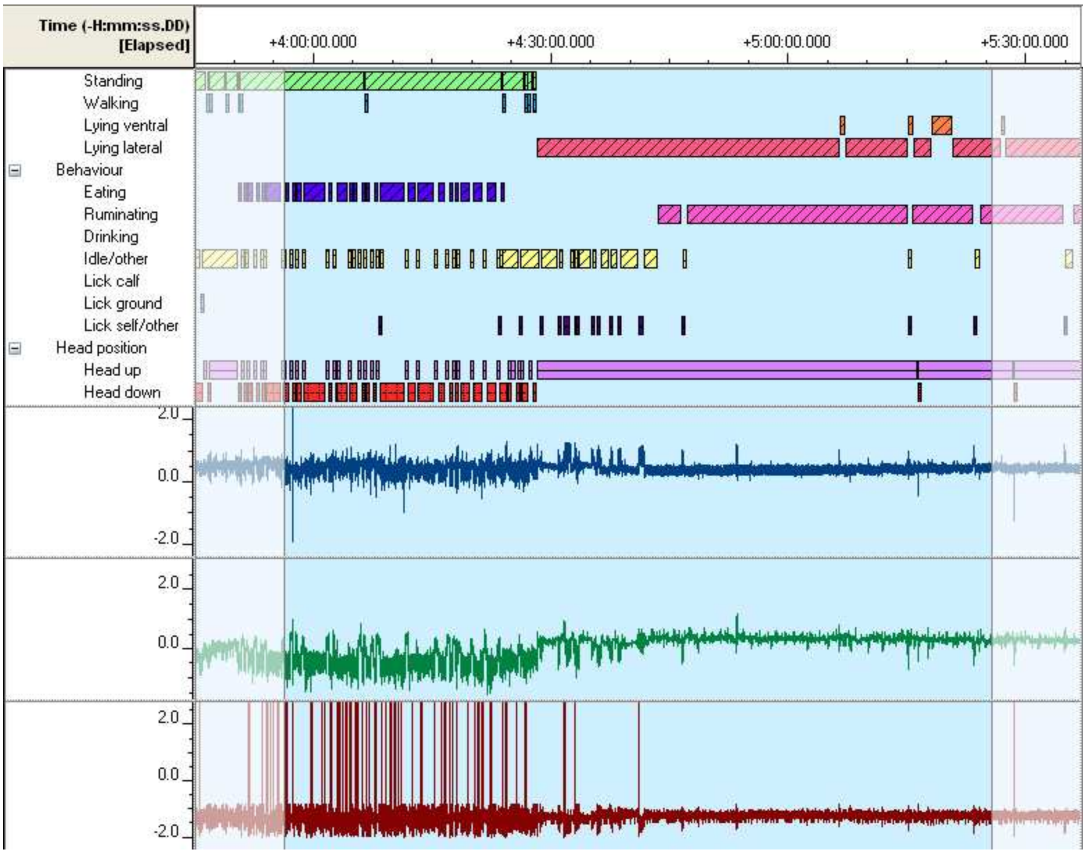

Figure 6.09
Output from the Observer XT showing behavioural states of cow 53, aligned with three axes of accelerometer data. Blue = x, green = y and red = z. The transition from active, standing behaviours to lying is associated with a reduction in the amplitude of all three axes, and a slight increase in the values of the y axis.

6.3.5 Accelerometer data relating to behavioural states

The median accelerometer values from five intervals of eating and non-eating were calculated from cow 53 (Table 6.02).

Table 6.02 Median values of accelerometer data (g) from eating and non-eating intervals

Interval	X	y	z	Duration (s)
Eat 1	0.41	-0.73	-1.35	20
Eat 2	0.42	-0.55	-1.25	49
Eat 3	0.40	-0.45	-1.15	27
Eat 4	0.46	-0.44	-1.18	25
Eat 5	0.33	-0.51	-1.14	52
Range	0.33:0.46	-0.73:-0.44	-1.35:-1.14	
Non-eat 1	0.51	0.12	-1.14	21
Non-eat 2	0.51	0.13	-1.14	17
Non-eat 3	0.53	0.04	-1.14	21
Non-eat 4	0.49	0.19	-1.15	22
Non-eat 5	0.48	0.23	-1.17	47
Range	0.48:0.53	0.04:0.23	-1.17:-1.14	

The median of the x and y axes values were different during eating compared to non-eating intervals but the z-axis data remained similar throughout. There was no overlap between the ranges of the y-axis data so these was used to define a simple rule: Eating (1); y = -2.0:-0.45g and not eating; (0) y = -0.445:0.45g.

The difference in lying and standing values was treated in a similar way. However, fewer intervals were summarised due to their longer duration (Table 6.03).

Table 6.03 Median values of accelerometer data from lying and standing intervals

Interval	x	y	z	Duration
Lie 1	0.70	0.27	-1.37	1.3 h
Lie 2	0.64	0.19	-1.30	2.1 h
Lie 3	0.55	0.16	-1.19	2.0 h
Range	0.55:0.70	0.16:0.27	-1.37:-1.19	
Stand 1	0.60	-0.21	-1.28	1.2 h
Stand 2	0.64	-0.16	-1.30	1.8 h
Stand 3	0.64	0.01	-1.28	2.0 h
Range	0.60:0.64	-0.21:0.01	-1.30:-1.28	

The ranges of the median values calculated from standing and lying intervals overlapped for the x and z axes, but again the y axis provided two distinct ranges that were used to define a basic rule: Standing eating; y = -2.0:-0.45, standing not eating; y = -0.445:0.1 and lying; y = 0.105:2.0.

6.3.6 Testing accuracy of behavioural classification

The results from the raw data showed some degree of correspondence between the rule classification and actual behaviour observed on the video. A section of this analysis is illustrated in the central columns of Table 6.04. From looking at these results, it was apparent that there was an offset of approximately ten seconds between the accelerometer and behaviour data. The addition of ten seconds to the behaviour resulted in a large improvement in the number of matches.

Table 6.04 Comparison of behavioural state determined from accelerometer data and actual state from video analysis. The original data are shown in the central columns. The data with a 10-s offset are shown on right. Dark green = true positive. Light green = true negative.

Time (min)	Median	Eating rule (1/0)	Actual (1/0)	Eating rule (1/0)	Actual (1/0) +10s
0.00	-0.79	1	0	1	1
0.17	-0.13	0	1	0	0
0.33	-0.66	1	1	1	1
0.50	-0.57	1	0	1	1
0.67	-0.10	0	0	0	0
0.83	0.00	0	0	0	0
1.00	-0.05	0	0	0	0
1.17	-0.04	0	1	0	0
1.33	-0.70	1	1	1	1
1.50	-0.78	1	1	1	1
1.67	-0.72	1	1	1	1
1.83	-0.54	1	0	1	1
2.00	-0.26	0	1	0	0
2.17	-0.78	1	1	1	1
2.33	-0.64	1	0	1	1
2.50	-0.08	0	0	0	0
2.67	0.09	0	0	0	0
2.83	0.03	0	1	0	0
3.00	-0.61	1	1	1	1
3.17	-0.57	1	0	1	1
3.33	-0.07	0	0	0	0
3.50	-0.16	0	0	0	0

No offset was observed when the second rule was tested using the same approach. Eating was not included, to allow the sensitivity and specificity of this rule to be calculated, leaving standing and lying as the two possible states (Table 6.05).

Table 6.05 Comparison of behavioural state determined from accelerometer data and actual state from video analysis. Dark green = true positive. Light green = true negative.

Time (min)	Median	Standing rule (1/0)	Actual (1/0)
40.00	0.33	0	0
40.17	0.22	0	0
40.33	0.28	0	0
40.50	0.02	1	0
40.67	0.31	0	0
40.83	0.33	0	0
41.00	0.32	0	0
41.17	0.30	0	0
41.33	0.28	0	0
41.50	0.26	0	0
41.67	0.30	0	0
41.83	0.31	0	0
42.00	-0.01	1	1
42.17	-0.35	1	1
42.33	-0.35	1	1
42.50	-0.12	1	1
42.67	-0.17	1	1
42.83	-0.15	1	1
43.00	-0.28	1	1
43.17	-0.30	1	1
43.33	-0.60	1	1
43.50	-0.35	1	1

The sensitivity and specificity of each rule was calculated from the hour of test data. In the case of eating, this was done for both the original and ten-second offset datasets (Table 6.06).

Table 6.06 Quantification of the success of using y-axis accelerometer data to identify eating behaviour in single test recording

Rule		Sensitivity (%)	Specificity (%)
1	Eat/not eat	80.6	72.4
1	Eat/not eat + 10s	95.7	89.5
2	Stand/lie	93.5	93.8

6.4 Discussion

The visualisations of behavioural states aligned with the outputs from the accelerometers were extremely helpful for the interpretation of this information and investigating an appropriate sampling frequency. Sampling frequencies vary greatly between existing studies, depending on the specific system under investigation. However, a frequency of 1 Hz appears to be adequate for the purpose of identifying behavioural states in dairy cows.

Visualising data also identified some issues with extremely high values affecting a proportion of the recordings. This problem was mainly seen in the z-axis data, of which 72.2% files were rejected and the y-axis appeared the most reliable with only 16.7% of files affected. However, this is still a significant proportion of the data and would need to be resolved before these collars could be used on a larger scale.

In addition to having the least abnormal values, the y-axis also appeared to be the most useful for identifying different behavioural states and was used for all further analysis. Changes in accelerometer output visualised against behavioural states were used as a starting point for the investigation of the relationship between behavioural states and the values of the y-axis. This appeared to mainly indicate movement or changes in position of the head and showed differences associated with eating and lying. Rules were developed and tested for the classification of eating and shown to have a fairly good accuracy at classifying accelerometer streams into eating and non-eating on the basis of the value of the y-axis. This was related to the angle of the head and when a video playback was watched of a cow eating, the angle of the head could be seen to clearly correspond with the values of this axis. The Ethosys system developed by Scheibe *et al.* (1998) has been used to identify hay uptake and grazing in cows and horses. Grazing was identified in a very similar way to eating in this study, as the same lowered head position changes the values along the y-axis. Scheibe and Gromann (2006) also used a similar method but calculated a mean average value in place of the median.

Another threshold was added to identify lying behaviour and this was also fairly successful, although only two individuals were studied. A comparison of more cows would be needed to establish if these rules can be generalised between animals or if they may require slight adjustments for each individual. However, the studies using Ethosys do not mention any individual differences, so it is likely that these behaviours can be identified in the same way between individuals (Langbein *et al.*, 1998a; Langbein *et al.*, 1998b; Scheibe *et al.*, 1998; Scheibe and Gromann, 2006).

The attachment of the accelerometers using a collar around the neck may limit the behaviours that can be distinguished from the data recorded. Other studies have used accelerometers attached to the legs of cows which have allowed step counts to be measured and made it possible to identify signs of lameness from the spectral analysis of the outputs (Scheibe and Gromann, 2006). Behaviours involving the tail cannot be measured by this system either but, if accelerometers could somehow be attached to the tail, this could be a useful method of recording tail movements and using this to aid calving prediction. However, attachment to the tail may irritate the cow and a robust method of attachment would be required to prevent damage or detachment of the device.

This area of research has huge potential for various applications and more advanced methodology may allow for the more accurate definition of behavioural transitions or for the recognition of a larger number of behavioural states and events from the accelerometer data. Accelerometers have excellent potential for studying wild free-ranging terrestrial and aquatic animals for research that cannot be done using live or video observations, or for studying a large number of individuals (i.e. dairy cows on a commercial farm). Even the simple measures that can currently be recorded make accelerometers a useful tool for behavioural research of farmed species.

Chapter 7: Heart rate recordings during late gestation

7.1 Introduction

One of the main physiological adaptations that occurs during gestation and parturition involves alterations in cardiac function to cope with the increased blood volume and changes in metabolism.

Changes in the heart rate of cattle can be associated with emotional stressors, such as separation from calves (Stehulova *et al.*, 2008) and handling stress (Waiblinger *et al.*, 2004), as well as physical stressors, such as heat stress (Beatty *et al.*, 2006), high milk yields (Hirose, 2002; Knight *et al.*, 2004), mastitis (Vangroenweghe *et al.*, 2004; Wagner and Apley, 2004) and exercise (Davidson and Beede, 2003). This shows that although heart rate may be a useful index of cow condition, it is influenced by a wide range of variables that could hide any changes of potential interest. Recently there has been a lot of interest in using indices of heart rate variability (HRV) to identify more subtle changes in heart function, that may not be detected from heart rate data alone (Mohr *et al.*, 2002; Marchant-Forde and Marchant-Forde, 2004; von Borell *et al.*, 2007).

Underlying changes in physiology have the potential to provide useful additional information about the progress of pregnancy and timing of calving, which may not be expressed in behaviour. Also, behaviour is not straightforward to measure automatically but many systems have been successfully developed for remote measurement of heart rate (reviewed by von Borell *et al.*, 2007). This makes heart rate and heart rate variability potentially useful measures for the development of an automated monitoring system to predict the time and monitor progress of calving.

7.1.1 Heart rate regulation

Contractions during the cardiac cycle are stimulated by electrical impulses. The primary heart beat originates in the sinoatrial (S-A) node, also know as the pacemaker of the heart. The impulse generated spreads throughout the atria, causing them to contract. The impulse also excites the artrioventricular (A-V) node that controls contraction of the ventricles. This intrinsic regulation of the heart beat is outside nervous control but the rate of beats and strength of contractions are regulated by the autonomic nervous system (ANS) (Reece, 1997).

The ANS consists of two opposing nervous systems, the parasympathetic and the sympathetic nervous system. Stimulation of the parasympathetic nerves tends to reduce the action of the heart. It does this by decreasing the force and rate of contraction, and the rate of conduction of impulses within the heart. This causes a reduction in the flow of blood through the arteries which leave the heart. Sympathetic stimulation increases heart activity by increasing the force and rate of contraction and the rate of impulse conduction, causing an increase in blood flow from the heart (Frandson and Spurgeon, 1992). The parasympathetic and sympathetic nervous systems regulate heart rate in this way via the S-A node (Figure 7.01).

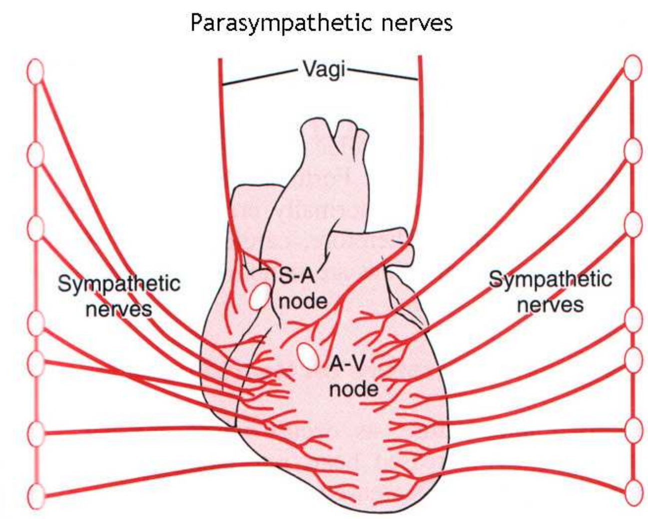

Figure 7.01
Innervations of the heart, showing the S-A and A-V nodes, and the parasympathetic and sympathetic nerves that make up the ANS (adapted from Guyton and Hall, 2000).

Rapid changes in heart rate are caused by shifts in parasympathetic regulation. The S-A node responds to these shifts within one or two heart beats, but its overall effects are relatively short-lived. These changes generally occur within five seconds whereas cardiac responses to sympathetic nervous system regulation occur more slowly, with initial response delays of up to five seconds, followed by a progressive change and maximum response after 20 – 30 seconds (von Borell *et al.*, 2007).

Heart rate at any point in time represents the net interaction between parasympathetic and sympathetic regulation, as both regulatory systems act to maintain heart rate within a defined range and respond to challenges (von Borell *et al.*, 2007). In a normal healthy individual, both of these work simultaneously and result in a heart rate with relatively high variability between each heart beat (Figure 7.02).

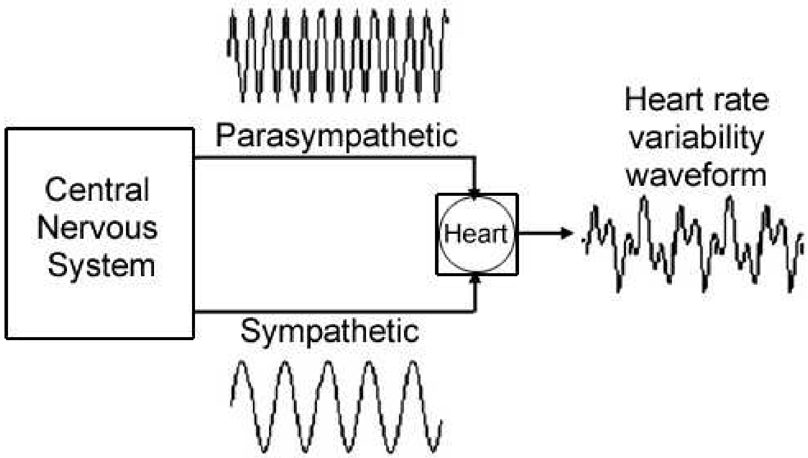

Figure 7.02
The central nervous system is split into two branches with opposing influences on heart rate. The parasympathetic nervous system tends to reduce the action of the heart, while the sympathetic nervous system increases heart activity. The simultaneous action of both systems results in a highly variable waveform (adapted from von Borell *et al.*, 2007).

7.1.2 Measuring heart rate

The electrical activity that controls the contraction and relaxation of the heart muscle spreads into the surrounding tissues so can be detected and recorded from the surface of the body. This is called electrocardiography (Frandson and Spurgeon, 1992). Electrocardiography is a well-established method for measuring heart activity. The output recorded is called an electrocardiogram, which shows a series of waves of electrical activity (Figure 7.03).

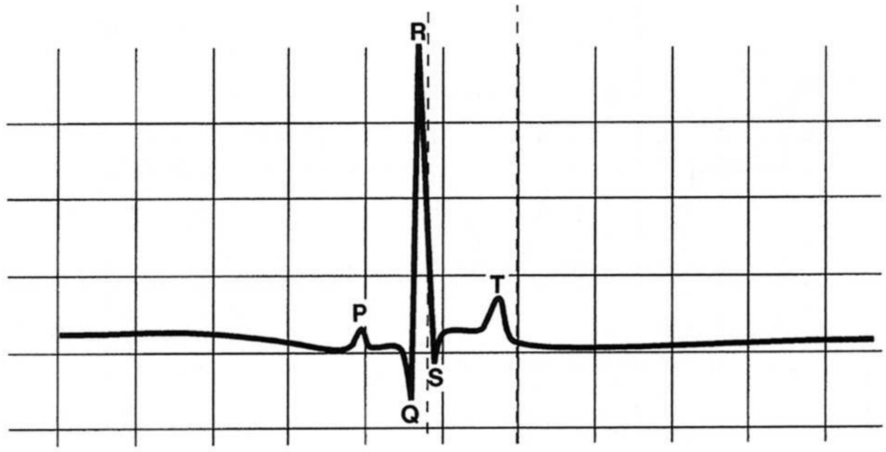

Figure 7.03
The general shape of the electrical activity recorded for a single heart beat using electrocardiography. The features are labelled with the letters P-T and represent different points during the cardiac cycle. The important feature for heart rate recording is the R-peak. Intervals between these peaks are used to calculate heart rate.

The features of the electrocardiograph output are labelled to help descriptions of each part for diagnostic purposes. The P-wave is caused by the spread of electrical activity from the S-A node throughout the atrial muscle, that causes the wave of depolarisation associated with contraction of the atria. The QRS complex coincides with the spread of electrical impulse over the A-V node that initiates ventricular systole. The T-wave is caused by repolarisation of the ventricles and marks the end of ventricular systole (Frandson and Spurgeon, 1992).

Heart rate via electrocardiography can be measured using a variety of methods and devices. However, the main feature used for measuring heart rate by most of these is the R-peak. Output from almost all electrocardiograph recording devices can be used to give a summary of the duration of intervals between consecutive peaks, called RR intervals. RR interval data can be used to calculate simple measures of heart rate, such as the maximum, minimum and mean.

Increases in average heart rate, or decreases in average RR interval, during gestation have been found in studies of humans (van Oppen *et al.*, 1996), sheep (Rosenfeld, 1977) and pigs (Marchant-Forde and Marchant-Forde, 2004) but this has not been investigated specifically in dairy cows. However, it is expected that they will also show a decrease in minimum, maximum and average RR intervals during gestation, and that measurable differences will be seen between a month before and a week before calving. Van Oppen *et al.* (1996) measured a decrease in the average heart rates of women six weeks postpartum, which suggests that heart rates will decrease following parturition.

7.1.3 Measuring heart rate variability

Changes in heart rate can often provide useful information about physiological and emotional states. However, although a raise in heart rate is mainly caused by an increase in sympathetic activity it may also result from a decrease in parasympathetic regulation, or from a combination of both. Simple measurements of heart rate cannot be used to distinguish the contribution of each regulatory system but heart rate variability analysis allows a much more detailed examination. This is especially useful for measuring states that might have an impact on sympathovagal balance without any noticeable change in heart rate (von Borell *et al.*, 2007).

Most studies involving HRV analysis focus on measures in the time and frequency domains. Time domain measures of heart rate variability are the simplest variables to calculate and describe the statistical variability in the RR interval data. These can be broadly divided into two types; those derived from the RR intervals themselves, and those derived from the differences between successive RR intervals. Table 7.01 summarises the statistical measures in the time domain.

Table 7.01 Statistical time domain measures of HRV (adapted from Camm *et al.*, 1996)

Variable	Unit	Description
SDNN	ms	Standard deviation of all RR intervals
SDANN	ms	Standard deviation of the means of RR intervals in all 5-min segments of the entire recording
RMSSD	ms	Root means squared of successive differences: the square root of the mean of the sum of the squares of differences between successive RR-intervals
$SDNN_{index}$	ms	Mean of all the standard deviations of all RR intervals for all 5-min segments of the entire recording (24h)
NN50count		Number of pairs of adjacent RR intervals differing by more than 50ms in the entire recording
pNN50	%	Percentage of pairs of successive RR intervals differing by more than 50ms

More complex analyses can be conducted by calculating geometric measures or frequency components from the data; these are described in detail by von Borell *et al.* (2007). Frequency domain analysis examines how the power (or variance) is distributed across frequencies. The most commonly used method for this type of analysis is the Fast Fourier transformation (FFT), which breaks down a single waveform into its sine and cosine components. The resulting power spectral density (PSD) can then be used to calculate a number of different variables (Table 7.02).

Table 7.02 Frequency domain measures of HRV suitable for analysis of short-term recordings (5 minutes) (adapted from Camm *et al.*, 1996)

Variable	Unit	Description	Frequency range
5 min total power	ms^2	Variance of RR intervals over the recording period	
VLF	ms^2	Power in very low frequency range	≤ 0.04 Hz
LF	ms^2	Power in low frequency range	0.04-0.15 Hz
LFnorm		LF power in normalised units LF/(total power-VLF) × 100	
HF	ms^2	Power in high frequency range	0.15-0.4 Hz
HFnorm		HF power in normalised units HF/(total power-VLF) × 100	
LF/HF		Ratio of LF/HF (both measured in ms^2)	

The use of heart rate variability analysis in studies of farm animal species was reviewed by von Borrel *et al.*, (2007). In cattle, heart rate variability has been used to study differences between breeds and different milking systems, to investigate if an automatic milking system caused chronic stress compared with a herringbone parlour. Time domain variables measured were heart rate, RMSSD and SDNN, and in the frequency domain, HFnorm, LFnorm and LF/HF were calculated. Heart rates were higher and heart rate variability in the time and frequency domains was lower in Simmental than Brown Swiss cows. Differences in the linear and nonlinear domains were found between cows milked in an automatic milking system and those milked in a herringbone parlour. The breed differences could possibly be explained by the variation in heart rate and heart rate variability seen with different body weights. Variations at different times of day were also found, but there was no effect of milk yield, stage of lactation or stage of pregnancy (Hagen *et al.*, 2005). Significant changes in the frequency domain have been found between healthy cows and those infected with bovine spongiform encephalopathy. These changes were observed months before any clinical signs of disease were present, suggesting that changes in heart rate variability could be an early indicator of disease (Pomfrett *et al.*, 2004). Minero *et al.* (2001) looked at the heart rate variability of cows at different ages and found a decrease in all of the variables calculated as the ages increased from calves to heifers, and then adults. Mohr *et al.* (2002) looked at the heart rate variability of three groups of calves; with no obvious stress load, external stress from high temperature and insect irritation, or internal stress from illness. No differences in heart rate variability were found in the time or frequency domains, but the non-linear analysis showed differences between the groups. Two groups of pregnant cows were also compared; 21 lactating and 10 non-lactating. Again, no significant differences were found in the time and frequency domains of heart rate variability, but non-linear differences were observed.

A study which looked at the cardiac activity of pigs throughout pregnancy found changes in both the time and frequency domain indices of heart rate variability. More specifically, decreases in RMSSD and SDNN were recorded as gestation progressed. However, no measurements were made following parturition (Marchant-Forde and Marchant-Forde, 2004). In studies of humans, heart rate variability is also reduced during pregnancy in both the time (Ekholm *et al.*, 1993) and frequency domain measures (Yang *et al.*, 2000).

7.1.4 Research aims

The overall aim of this chapter was to establish if there is a change in the heart rate or heart rate variability of dairy cows during the last six to ten weeks of pregnancy.

This was divided into more specific research aims, listed below;

1. To summarise heart rate data to look for any variations between different parities and levels of milk yield, or with different calving events.

2. To identify any linear changes in heart rate variables during late gestation, from about two months before until the week before calving

3. To compare heart rate variables a month before parturition with the final week before parturition to identify potential changes associated with approaching parturition.

4. To identify any differences in heart rate variables between the last recording before parturition and a recording made after parturition.

7.2 Materials and Methods

7.2.1 Selection of cows

This study was conducted towards the end of the calving season, so there were a limited number of cows available. All of the remaining multiparous cows that were due to calve were used, but heifers were not included. Heart rates vary with age (Thomas and Moore, 1951; Rezakhani *et al.*, 2004) and milk yield (Hirose, 2002) so these variables were extracted from the farm records to see if they could explain any variation between individuals.

7.2.2 Electrocardiogram recordings

Data were collected from February-April 2008 by the research technician at Langhill Farm. Electrocardiogram recordings were made once a week, for six to ten weeks before parturition and one recording after. A Televet 100 ECG device connected to a laptop was used to make the recordings (Kruuse, 2007). Two pairs of electrodes were used, attached in the positions illustrated in Figure 7.04.

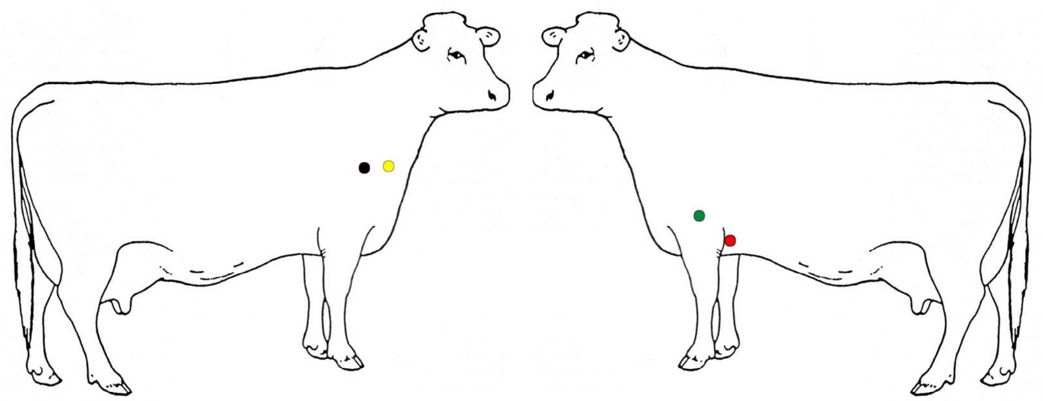

Figure 7.04
Sites of electrode attachment for ECG recordings. Red: on the left side of the body, just behind the point of the elbow. Green: on the left humerus, near the red. Yellow: On the right side, in arc from jugular furrow to top of humerus. Black (earth): Next to yellow on right side, slightly further back.

The sites of electrode attachment were clipped to improve the signal obtained and electrode pads containing conductive gel were used (Ambu Ltd., Cambridgeshire).

Cows were restrained in a crush during the recordings, so all electrocardiograms were measured while standing. Recordings were made using Televet software (Rösch and Associates Information Engineering GmbH, 2007) and were between 20-25 minutes in duration. The sampling rate was 500 Hz. R-peaks were detected by the software, using a rule-based R-wave detector, and this information was exported as RR interval data for analysis. The ECG traces recorded appeared to show the heart rate clearly (Figure 7.05).

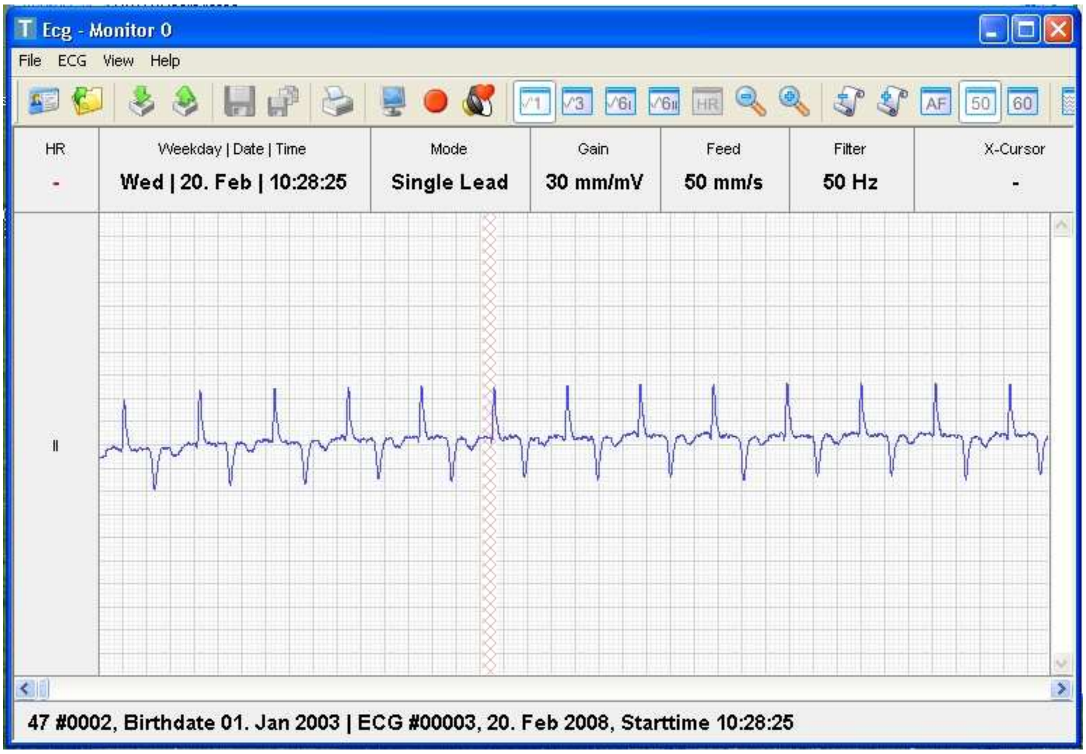

Figure 7.05
Screen shot saved from Televet software showing part of an electrocardiogram trace from cow 47. The heart beats could be seen clearly and the R-peaks could be detected by the software to calculate RR intervals.

7.2.3 Selection of interval used for analysis

The first 5 minutes of data were not used to reduce the effect of handling. This was decided after a preliminary examination of the data and from durations used in other studies (Stewart *et al.*, 2008). The RR intervals from the subsequent 5 minutes were exported and used to calculate the heart rate variables.

Five-minute samples were used, as this is the standard duration used in a number of studies where 24-hour monitoring is not possible. This is an accepted minimum recording duration, and results from 5-minute recordings have been shown to be strongly correlated with 24-hour recordings (Sloan *et al.*, 1994; Min *et al.*, 2008).

7.2.4 Identification and correction of anomalies

Variables calculated from the RR interval data are susceptible to artefacts caused by missed beats or electrode movements that can hide the effects of interest (Marchant-Forde *et al.*, 2004). Therefore, it was important to identify and correct these artefacts before the analysis conducted. Other studies have used software (Liao *et al.*, 1995; Mohr *et al.*, 2002; Stewart *et al.*, 2008) or visual inspection (Goldberger *et al.*, 2001; Visser *et al.*, 2002; Pomfrett *et al.*, 2004; Marchant-Forde *et al.*, 2004; Norman *et al.*, 2005; Min *et al.*, 2008) to find errors in heart rate data. Various algorithms have been developed for both retrospective (Cheung, 1981; Sapoznikov *et al.*, 1992; Berntson and Stowell, 1998; Salo *et al.*, 2001) and real-time (Rand *et al.*, 2007) identification of anomalies, but many studies use fairly simple rules to identify abnormal intervals.

The most basic methods of identifying abnormal values are ‘wild point removal’, which is the rejection of values outside the normal range, and rejecting changes which are greater than a given duration (Hopster and Blokhuis, 1994). A slight modification to the same idea is the use of a maximum deviation, where changes of more than a given percentage of the previous interval are marked as abnormal (Cheung, 1981; Marchant-Forde *et al.*, 2004). This method using maximum deviations was used on the RR interval data, with a threshold of a maximum of 20% change between intervals. Therefore, if the difference between an RR interval and its previous neighbour was more than 20% of the previous interval, it was classified as abnormal.

Once anomalies have been identified, there are three main methods used to correct or edit them;

1. Deletion: removes non-normal RR intervals (optional replacement with previous normal interval)
2. Interpolation of degree 0: replace edited non-normal RR interval with a local average of previous accepted intervals.
3. Interpolation of degree 1: replace non-normal RR interval with points obtained from a fitted straight line of the normal intervals.

Deletion without replacement was used because the difference in effects of the different methods on the results obtained are relatively small (Salo *et al.*, 2001). Recordings with an error rate of more than 5% or with more than five adjacent abnormal intervals were rejected. This limit of 5% error has been used in other studies (Minero *et al.*, 2001; Mohr *et al.*, 2002), although some accepted higher rates of 6% (Stewart *et al.*, 2008) and 15% (Lucreziotti *et al.*, 2000).

7.2.5 Calculation of heart rate variables

Several time domain variables were calculated from the 5-minute samples of RR intervals. Variables were chosen that are widely applied in the literature. Mean RR and mean HR are directly inversely related, so the results are the same for these two variables. The variables calculated are summarised in Table 7.03.

Table 7.03 Heart rate variables calculated from 5-minute RR interval data

Variable	Units	Description
RR-max	ms	Maximum duration of RR-interval
RR-min	ms	Minimum duration of RR-interval
Mean RR	ms	Mean RR-interval duration over entire 5-minute recording
Mean HR	bpm	Mean heart rate over entire 5-minute recording
SDNN	ms	Standard deviation of all RR-intervals
RMSSD	ms	The square root of the mean of the sum of the squares of differences between successive RR-intervals
pNN50	%	Percentage of pairs of successive RR-intervals differing by more than 50ms

7.2.6 Statistical analyses

Summary statistics were calculated according to parity and milk yield to show any variation due to these variables. The sample sizes were too small for statistical analysis but potential trends were identified. Recordings from 35-39 days before calving were used to minimise any effects of parturition.

To see if the heart rate variables before calving varied according to the difficulty of the calving, number of offspring, or other problems, the final recordings before calving (0-6 days) were summarised for each type of calving. The sample sizes were too small for statistical methods to be applied but general trends were shown.

Variables with a normal distribution were tested for a relationship against days before calving in a general linear model (GLM). No non-parametric equivalent of this analysis was available because of the repeated measures on the same cows. Cow identification numbers were included as a random factor in the GLM and days were included as days relative to calving, so were all negative. No post-calving values were included because these were not expected to follow the same relationship as during the period before calving.

To investigate differences between the variables at the closest point to calving (0-6 days before) and about a month earlier (35-39 days before), these values were compared for each cow. Normally-distributed data were analysed using paired t-tests, and Wilcoxon signed rank tests were used for non-parametric data. The same tests were used to compare the final measurements before calving (0-6 days before) with recordings made 1-7 days after calving.

7.3 Results

7.3.1 Summary of data collected

A total of 109 recordings were made from 12 cows with 7-11 recordings per cow (median = 9). Only one cow did not calve successfully and had a dead calf that had become mummified. Recordings from this cow were excluded from any analyses that focussed on the time before and around calving.

No anomalies were detected in 52 of the 109 recordings. 15 recordings (14.8%) were rejected because they included too many errors. Fourteen of these had more than the threshold of 5% total errors, and one included more than five consecutive unusual intervals. The remaining 94 recordings were edited to minimise the effect of anomalies before use in the analyses.

7.3.2 Variation associated with parity, milk yield and calving

Most cows had a parity of four so these formed the largest group. Two cows of higher parities and two of lower parities formed another two groups. The 305-day milk yield data were used to sort the cows into classes of relative milk yields; low (< 9000 kg), medium (9000-9900 kg) and high (>9900 kg). The information collected about these animals is summarised in Table 7.04.

Table 7.04 Parities and relative yields of cows in study

Cow ID	Parity	Yield: 305d lactation (kg)	Total yield (kg)	Days in milk	Relative yield (Low/Med/High)
47	4	9873	10656	362	Med
60	4	11970	12408	319	High
74	11	6719	7046	338	Low
83	4	9746	10204	325	Med
97	2	9969	14449	463	High
114	4	11435	12521	409	High
115	2	6138	6670	332	Low
125	5	8023	8023	284	Low
141	4	12065	14260	406	High
199	4	8287	8938	335	Low
214	4	9430	9737	318	Med
250	4	9880	10073	316	Med
Mean	4.3	9461.3	10415.4	350.6	
Range	4 - 11	6138 - 12065	6670 - 14449	284 - 463	

Summaries of the basic heart rate variables by parity and relative milk yield are shown in Tables 7.05 and 7.06, respectively.

Table 7.05 Mean (± S.E.) heart rate summary data of different parity groups measured 35-39 days before parturition.

Parity	n	RR max	RR min	Mean RR	Mean HR
2-3	2	787.0 ± 17.0	629.0 ± 29.0	723.6 ± 20.1	83.0 ± 2.3
4	8	935.0 ± 60.4	721.3 ± 44.0	849.9 ± 48.5	72.2 ± 4.1
5-11	2	994.0 ± 186.0	791.0 ± 73.0	931.7 ± 163.6	66.5 ± 11.7
All parities	12	920.2 ± 49.4	717.5 ± 33.4	842.5 ± 41.8	73.0 ± 3.4

Table 7.06 Mean (± S.E.) heart rate summary data of different milk yield groups measured 35-39 days before parturition.

Yield	n	RR max	RR min	Mean RR	Mean HR
Low	4	991.0 ± 106.8	794.5 ± 86.2	911.4 ± 102.3	68.4 ± 7.8
Med	4	849.0 ± 52.4	675.0 ± 26.2	791.5 ± 48.7	76.8 ± 5.1
High	4	920.5 ± 96.6	683.0 ± 34.6	824.5 ± 61.9	73.9 ± 5.2
All yields	12	920.2 ± 49.4	717.5 ± 33.4	842.5 ± 41.8	73.0 ± 3.4

The heart rate variability measures were also summarised by parity and relative milk yield, in Tables 7.07 and 7.08, respectively.

Table 7.07 Mean (± S.E.) heart rate variability data of different parity groups measured 35-39 days before parturition.

Parity	n	SDNN	RMSSD	pNN50
2-3	2	35.0 ± 16.8	9.3 ± 1.5	0.3 ± 0.3
4	8	37.0 ± 5.1	20.3 ± 5.3	6.8 ± 4.2
5-11	2	33.2 ± 14.9	22.3 ± 17.4	7.1 ± 7.1
All parities	12	36.0 ± 4.4	18.8 ± 4.3	5.8 ± 3.0

Table 7.08 Mean (± S.E.) heart rate variability data of different milk yield groups measured 35-39 days before parturition.

Yield	n	SDNN	RMSSD	pNN50
Low	4	36.0 ± 8.2	19.2 ± 7.7	4.4 ± 3.4
Med	4	31.6 ± 5.3	11.9 ± 3.8	1.2 ± 1.1
High	4	40.4 ± 10.0	25.2 ± 10.0	11.7 ± 8.0
All yields	12	36.0 ± 4.4	18.8 ± 4.3	5.8 ± 3.0

The final recordings before calving (0-6 days) were grouped according to information about the calving to see if the heart rate data corresponded to any problems or differences between the calvings. The heart rate summary data are shown in Table 7.09 and heart rate variability measures in Table 7.10.

Table 7.09 Mean (±SEM) heart rate summary data of different parity groups measured during 0-6 days before calving.

Calving	n	RR max	RR min	Mean RR	Mean HR
Normal	6	769.0 ± 36.1	594.7 ± 31.5	699.6 ± 25.6	86.3 ± 2.8
Twins	2	595.0 ± 21.0	427.0 ± 1.0	534.6 ± 15.4	112.3 ± 3.2
Jack	3	882.7 ± 31.6	632.7 ± 29.4	767.6 ± 33.9	78.5 ± 3.3
Mummified calf	1	1006.0	808.0	912.3	65.8
All	12	788.2 ± 38.6	594.0 ± 32.7	706.8 ± 32.6	87.0 ± 4.2

Table 7.10 Mean (±SEM) heart rate variability data of different parity groups measured during 0-6 days before calving.

Calving	n	SDNN	RMSSD	pNN50
Normal	6	29.3 ± 5.4	9.4 ± 1.1	0.6 ± 0.2
Twins	2	29.5 ± 12.1	7.9 ± 0.5	0.5 ± 0.2
Jack	3	44.1 ± 6.3	16.1 ± 3.6	1.9 ± 1.0
Mummified calf	1	36.8	16.2	0.6
All	12	33.7 ± 3.8	11.4 ± 1.4	0.9 ± 0.3

The most interesting differences were seen in the RR interval data. The individual values were plotted to give a visual representation of differences that could potentially be significant with larger sample sizes (Figure 7.06).

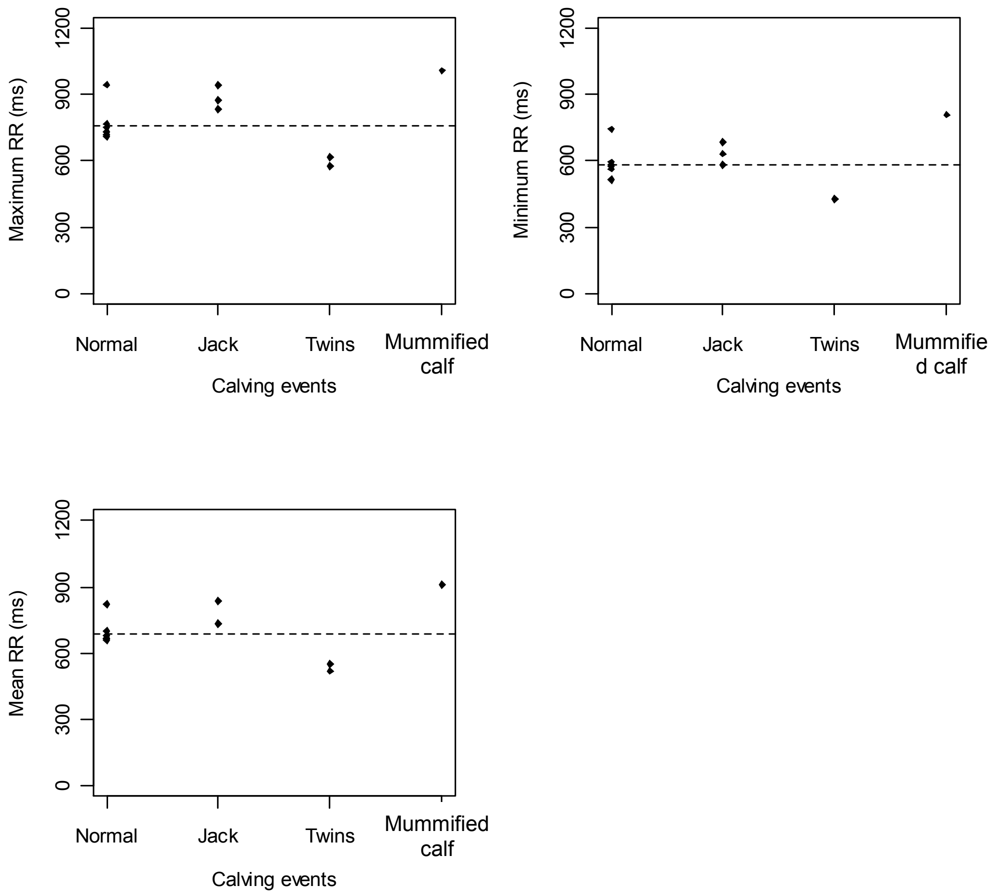

Figure 7.06
The maximum, minimum and mean RR interval values measured during the final week before calving, sorted by information about the calving. Normal calvings were single unassisted births, those assisted using a jack and cows which had twins are shown separately, and the cow with the mummified calf is shown separately.

7.3.3 Regression against days before calving

Five of the heart rate variables were normally distributed, so could be tested for a regression against days before calving. These were RR max, RR min, mean RR, mean HR and SDNN. The smoothed averages suggested that a quadratic function might fit the data more accurately than a linear function (Figure 7.07).

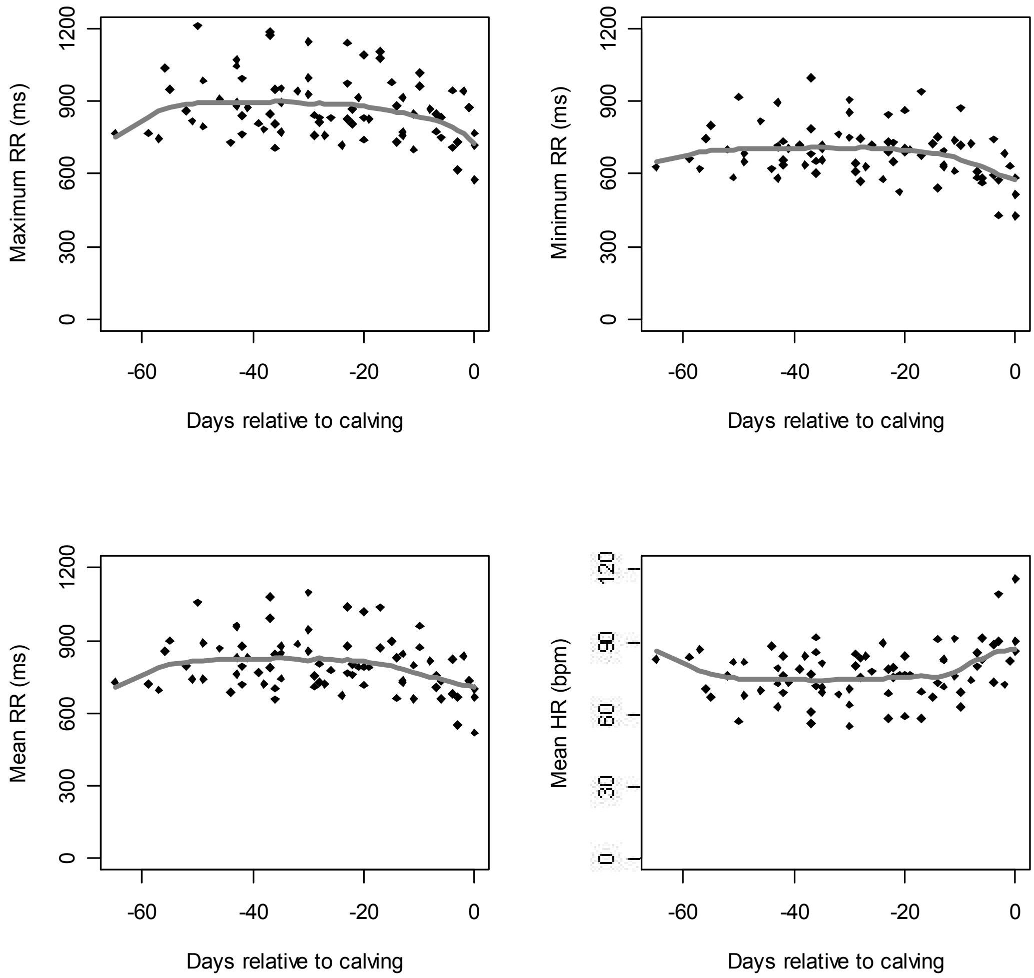

Figure 7.07
Each graph shows the smoothed average of the different heart rate variables against days relative to calving. The shape suggests that the relationship between these variables and the days before calving is not linear.

The model with the best fit for each of these four variables included both linear and quadratic components, and these results were significant ($p < 0.01$). The fitted lines are illustrated in Figure 7.08.

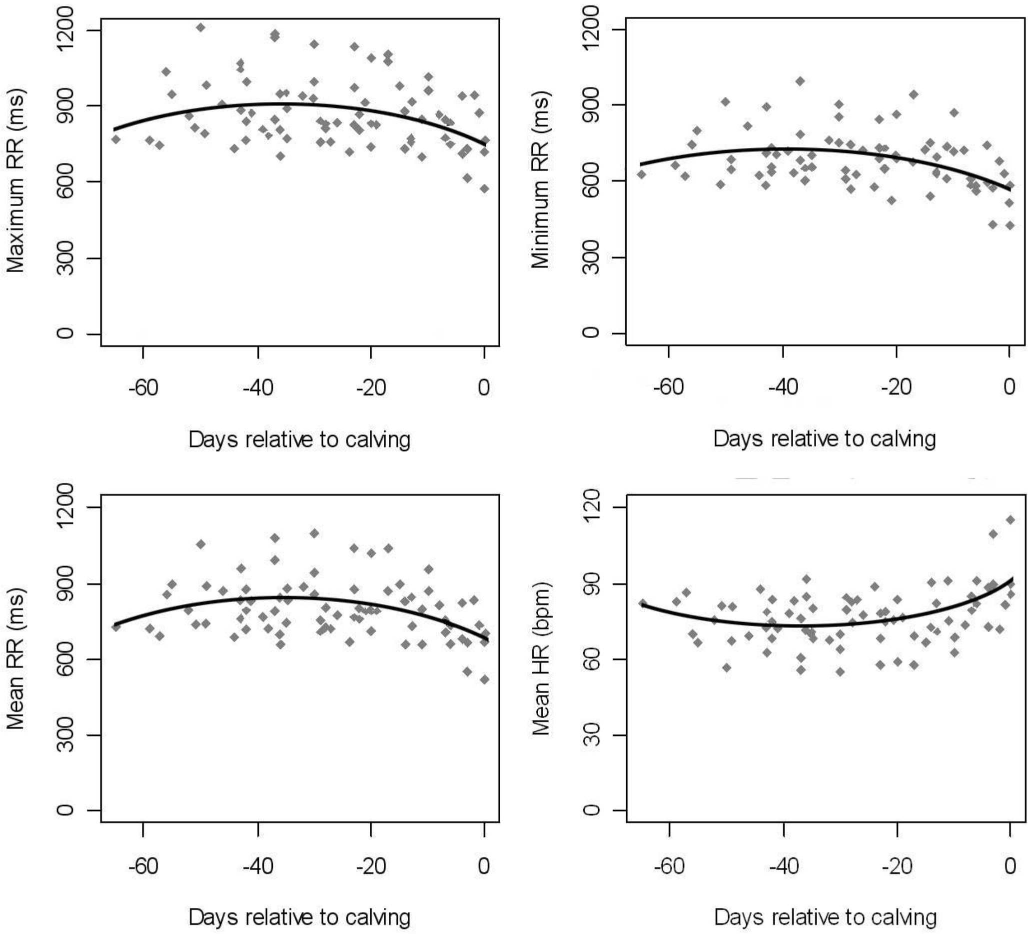

Figure 7.08
Each graph shows the regression of a different heart rate variable against days relative to calving. The spread of the data is large, but all of these trends are statistically significant. RR max ($p = 0.004$), RR min ($p < 0.001$), mean RR ($p < 0.001$) and mean HR ($p < 0.001$).

The standard deviation of the RR intervals was not significantly associated with days relative to calving ($p = 0.751$).

7.3.4 Comparison of month against week before calving

Significant decreases in RR max ($t = -3.71$, $df = 10$, $p = 0.04$), RR min ($t = 5.17$, $df = 10$, $p < 0.001$) and mean RR ($t = 4.26$, $df = 10$, $p = 0.002$) were found between 35-39 days and 0-6 days before calving (Figure 7.09).

The other variables in the study were compared using non-parametric tests but no significant differences were observed. These measures were SDNN ($p = 0.564$), RMSSD ($p = 0.743$) and pNN50 ($p = 0.844$).

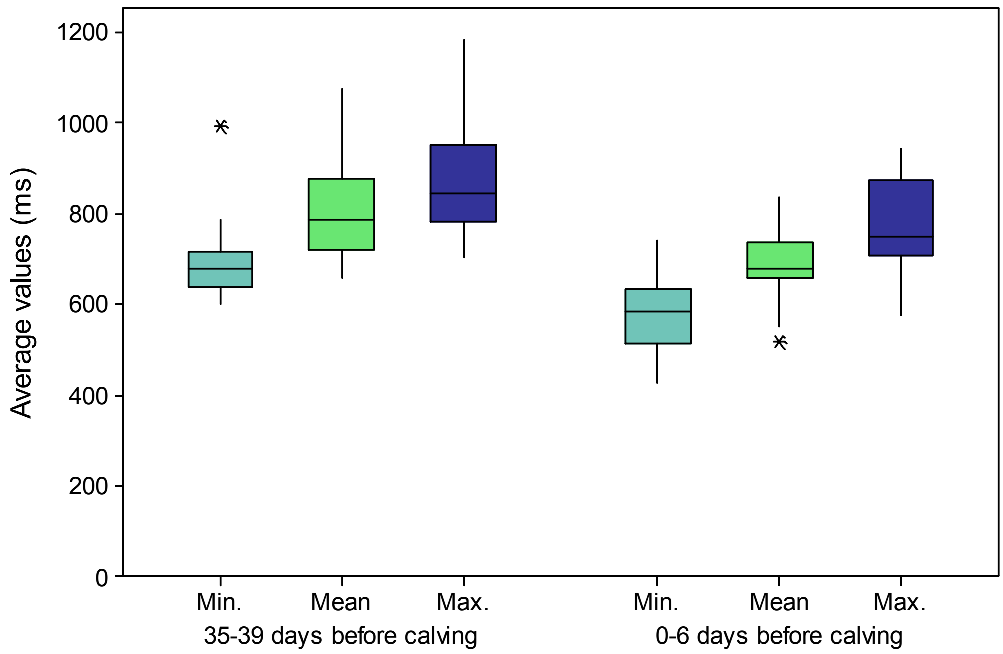

Figure 7.09
Box plots showing averages of RR min (light blue), RR max (dark blue) and mean RR (green) measured 35-39 days and 0-6 days before calving. All three were significantly lower during the final week before calving ($p < 0.05$).

7.3.5 Week before compared to week after calving

The RR max of the cows was significantly lower before calving, with a mean of 779.7 ± 117.0 ms, than after calving, when the mean was 876.7 ± 120.0 ms ($t = 2.42$, $df = 7$, $p = 0.046$). Similar changes were observed in the RR min, which increased between before and after calving ($t = 5.67$, $df = 7$, $p = 0.001$) and mean RR which also increased following calving ($t = 3.77$, $df = 7$, $p = 0.007$). These changes are shown in Figure 7.10.

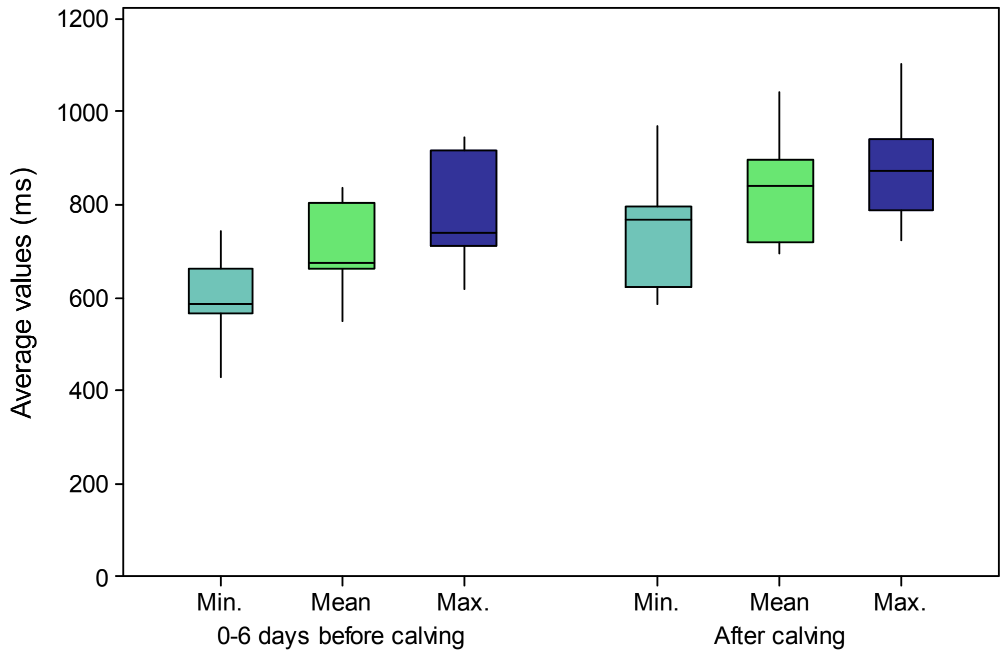

Figure 7.10
Averages of RR min (light blue), RR max (dark blue) and mean RR (green) measured 0-6 days before and 1-7 days after calving. All three were significantly higher the week after calving ($p < 0.05$).

The SDNN was also significantly different before and after calving, ($t = -2.47$, $p = 0.043$, d.f. = 7) with the mean being significantly higher 0-6 days before than 1-7 days after (Figure 7.11).

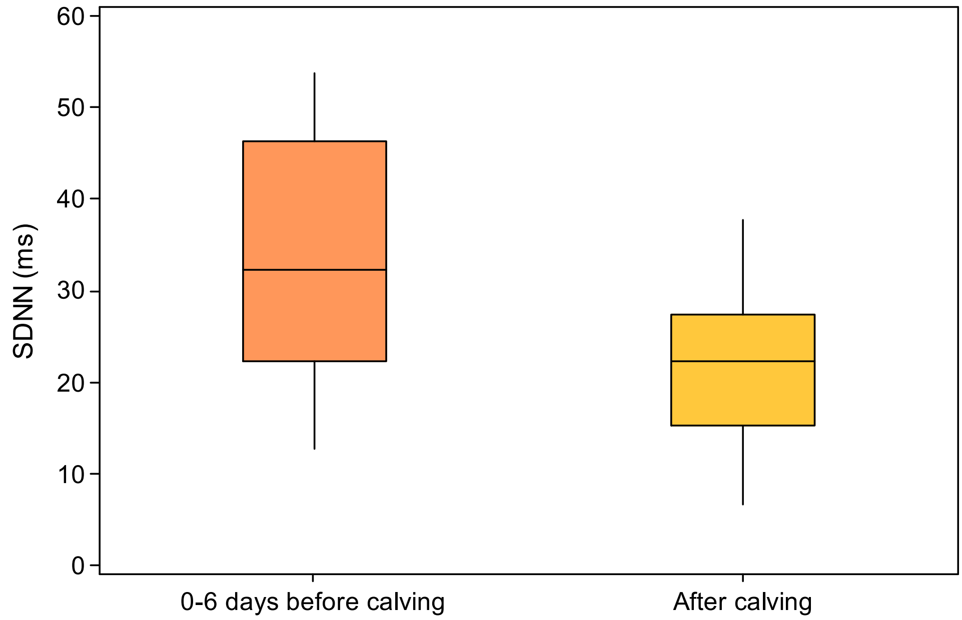

Figure 7.11
Average SDNN measured 0-6 days before and 1-7 days after calving ($p < 0.05$).

No significant changes in RMSSD ($p = 0.624$) and pNN50 ($p = 0.554$) were observed between 0-6 days before and 1-7 days after calving.

7.4 Discussion

7.4.1 Variations in heart rate with parity, yield and calving

There were not sufficient data to conduct any analyses on the variation in heart function of cows of different parities and milk yields. However, the data suggest there may be a trend for higher heart rates in younger animals. This would agree with the results of Rezakhani *et al.* (2004) who found that younger dairy cows had higher heart rates than older cows. This difference was attributed to the size of the heart; with the smaller hearts and lower stroke volumes of younger cows requiring a higher heart rate to achieve the same cardiac output (cardiac output = heart rate × stroke volume). Thomas and Moore (1951) also measured higher heart rates in heifers, than the rate seen in cows in their second to seventh lactations. Parity could be an important variable that needs to be taken into account when looking for trends in heart rate. Both the RMSSD and pNN50 measures of heart rate variability also appear to increase with parity but SDNN did not show any trend. This fits with the recommendations made by von Borell *et al.* (2007) that the age of subjects should be standardised and mentioned in any study of heart rate variability. The effect of age on heart rate variability was also highlighted as an area requiring further research. Some work has already been done in this area by Minero *et al.* (2001) who found a decrease in SDNN and RMSSD as age increased between dairy calves, heifers, and adults.

There was no apparent trend in the heart rates of cows with different levels of milk yield. Higher heart rates were expected in high-yielding cows but this was not observed in the small sample of cows studied. In a study of heart rates in non-pregnant lactating cows, average heart rate was positively correlated with milk yield, ranging from about 55–90 beats per minute with yields of 20–60 kg/day. When milking was stopped and cows went dry, heart rates fell to an average of 50 beats per minute (Hirose, 2002). No trends were seen in the heart rate variability measures in association with milk yield. In a study of heart rate variability in two different milking systems, no effect of milk yield on heart rate variability was found (Hagen *et al.*, 2005).

Half of the cows in the study calved without any problems. Two had twins, but otherwise these calvings were also without difficulties. Three cows were assisted using a calving jack and one cow had a mummified calf. The large proportion of normal calvings helps to establish a normal mean to compare the others to, but the rest of the samples are too small to determine any real differences. There are some trends in the data that would potentially be very interesting if a more data were available. The cows carrying twins had the lowest mean, minimum and maximum RR intervals before calving. This corresponds to higher heart rates than those with single calves, suggesting that carrying twins may require an increase in heart rate above that needed for a single calf. The cow with a mummified calf had relatively high values of mean, minimum and maximum RR interval, corresponding to a slow heart rate. This could be because she was no longer under the same physiological stress as the other cows that were still carrying live calves. The heart rate variability (SDNN, RMSSD and pNN50) was lower in the cows that had normal and twin calvings than in those that were assisted and had the mummified calf. The same trends were not seen as for the heart rate data.

7.4.2 Changes in heart activity during late pregnancy

The first research question was to investigate if there were linear changes in any of the heart rate variables studied from about two months before the end of gestation until calving. The variables used to measure changes in basic heart rate all showed the same regression results against time before calving as they are closely related to each other. An increase in average heart rate was expected towards end of gestation (corresponding to a decrease in average RR interval). This was observed but the change was relatively small, and although it was statistically significant it may not necessarily be biologically significant. Thomas and Moore (1951) found consistent increases in the heart rates of dairy cows, measured using a stethoscope, from 90 days before calving. This increased relatively slowly, by only 7 bpm from 81-90 days before until 31-40 days before, and then more quickly after that from 71.3 bpm (range = 60-84, n = 14) to 91.7 bpm (range 80-116, n = 9) between a month and a week before calving.

The regression of SDNN against days before calving was not significant. This was the only measure of heart rate variability which could be analysed in this way because the others were not normally distributed so there is no evidence that heart rate variability decreases during the last weeks of pregnancy. A study of pigs found an increase in mean heart rate throughout pregnancy and decreases in RMSSD and SDNN (Marchant-Forde and Marchant-Forde, 2004). It is possible that dairy cows show a different pattern of change in heart rate variability in comparison to pigs but it is equally likely that the changes were not captured within the time frame studied.

7.4.3 Comparison of month against week before calving

All of the variables were compared between recordings a month before and the final week before parturition. Significant decreases were measured in the mean, minimum and maximum RR intervals, so there was a definite increase in heart rate in the final week before calving. The average heart rate calculated 35-39 days before calving was 73.2 bpm, which increased to 87.2 bpm, 0-6 days before. This is a smaller increase than that measured by Thomas and Moore (1951) who recorded average heart rates of 71.3 bpm, 31-40 days before calving, and 91.7 bpm, 1-10 days before calving but the results are similar.

No significant results were found for measures of heart rate variability. When compared with data recorded from pigs at around the same times during gestation, they appear to show the same trend, at least in RMSSD. In this study RMSSD decreased from 16.9 ms, a month before parturition, to 11.0 ms, the week before. In pigs, RMSSD was 19.1 ms during week 11 of gestation (around one month before parturition) and decreased to 11.1 ms during week 15 (around a week before parturition) (Marchant-Forde and Marchant-Forde, 2004). The difference found in this study was slightly smaller and the lack of significance found may be due to the lower power of the non-parametric tests used. The SDNN showed only a small difference between 35-39 days (34.9 ms) and 0-6 days (33.4 ms) before calving. This difference was larger in sows between week 11 (approximately 33 ms) and week 15 (approximately 25 ms) of gestation (Marchant-Forde and Marchant-Forde, 2004).

7.4.4 Week before compared to week after calving

Again, all three of mean, minimum and maximum RR intervals were significantly different between these two time points. The average heart rate during the final week was 87.2 beats per minute, and this fell to 72.3 beats per minute during the week after calving. Some of the recordings after calving were not used because of their high error rates but the sample size of eight was sufficient. A study of the heart rates of goats around the time of parturition, measured at 30-minute intervals, found a decrease in heart rate on the day following parturition (Hydbring *et al.*, 1997). This represented a much more detailed analysis of the short-term variation during the days around parturition but the results from this study show that weekly measurements also capture this change following parturition.

SDNN was significantly higher when measured during the week before calving (33.4 ms), compared with the week after calving (21.94 ms). Heart rate variability was expected to be higher after calving as the cow recovered from this physiological challenge. However, it is possible that measuring this during the first week after calving, some only one or two days after, is too early for recovery to have started. The increased metabolic demands of lactation could also mean that changes are likely to take longer than a few days. This indicates why heart rate variability is an important measure in addition to heart rate because it might show different effects of the same physiological stressors.

7.4.5 Methodological considerations

The acceptable error rate was deliberately designed to be conservative to ensure that the effects of artefacts on the results was minimised. The decisions were made on the basis of work done in other studies of heart rate variability, as this is much more easily affected by artefacts than basic measures of heart rate. In this study, 15% of recordings were rejected due to a large number of values which were outside the expected deviation. Most studies do not specify how many recordings have an unacceptable error rate but Visser *et al.* (2002) reported a figure of 8%. This is likely to be lower than for the results presented here because visual correction of the data allowed some of the errors to be fixed. Manual correction was not possible in this study but appears to be a useful way to check the data collected and maximise the data that can be used.

Simple artefact correction would be an important feature of any system for use in a remote monitoring device. A number of measurement errors are unavoidable when using electrocardiography, especially when animals are moving around in a farm environment. This means that a method that is not too susceptible to artefacts is desirable.

The time studied was only from 6-10 weeks before calving. A significant linear increase in average heart rate was observed during this time but there was a lot of variation in the data and the differences observed were relatively small. However, significant changes were observed when heart rate values were compared between a month before and week before calving. The majority of the cardiovascular adaptation to pregnancy occurs during the first half of gestation (Knobil and Neill, 1998) so it is possible that this is when the largest changes in heart rate can be measured. A longer study starting from fertilisation and tracking changes throughout the entire gestation, like Marchant-Forde and Marchant-Forde (2004) conducted on farrowing sows, would show if this relationship holds true for cows. Recordings should be made from the beginning of gestation, if not before mating, and at regular intervals throughout. The changes after calving are also interesting, and it would be interesting to see the time course of the cardiovascular changes after parturition and how long it takes for heart rate to drop to normal, pre-pregnancy values. Another alternative study design would involve more frequent measurements during the final week before parturition and look for a sharp increase in heart rate which may indicate that calving in imminent, as seen in goats (Hydbring *et al.*, 1997).

7.4.6 Conclusions

In conclusion, parity and milk yield can have an influence on heart rate, so should be recorded and standardised in any future studies. There is some evidence to suggest differences in heart rate before normal calvings and those that require assistance, which would be an interesting subject for further study. Differences were found in the heart rates of cows during the final weeks of gestation but the individual variation was large and may hide the subtle changes in heart rate that are of interest.

Chapter 8: Discussion

The overall aim of this thesis was to investigate the use of behavioural, accelerometer and heart rate measurements to predict calving in dairy cows. Of these three types of measurement, behaviour was studied in the greatest detail and with the most promising results. Accelerometers showed a potential ability to identify lying, standing and eating behaviour. However, the weekly heart rate measurements did not provide any additional information regarding the progress of gestation and approach of calving. It is possible that recordings were too infrequent at weekly intervals and that more frequent measurement over a shorter time before calving would be more suitable.

The signs used by stockmen to predict calving and how long before calving these signs were noticed were investigated. The results provided a useful comparison against observations from the video recordings but also gave some insight into the decision-making process regarding when cows and heifers are assisted at calving. Many cows and heifers were not noticed to be close to calving before their calves were born or parts of the calf were already visible. However, in many cases signs were observed before this point. Tail lifting and restlessness were behaviours that were frequently observed by stockmen and were also found to be significant from the analysis of data collected from the video recordings.

The large number of cows and heifers that were assisted at calving was a slight concern and the results for when dams were assisted after the appearance of the calf's feet may suggest that assistance was not required in all cases. However, this is a difficult judgement to make and each individual case is different. This is why training and experience are essential for farm staff involved with the husbandry of cows.

It is also likely that some of these cases would have required assistance and may have suffered pain and discomfort (exceeding the level experienced during normal calving) as a result of calving difficulties, even if they were given assistance but especially if they were not assisted or if assistance was delayed. This is a concern for the welfare of these animals and it would be desirable to prevent this from happening as far as possible. Complete prevention is not a practical aim, but some farms have very low rates of calving difficulty and assistances rates are also very low in beef cattle, so it should be possible to reduce the levels of calving difficulty in dairy cows to some degree.

The analysis of behaviour from the video recordings showed some consistent changes between individual cows before calving. The most potentially useful behaviours for calving prediction appear to be the number of lying bouts and the duration of tail raising. Heifers showed changes in behaviour earlier than cows because the calving process takes longer the first time and these animals are not yet fully grown. This is normal but parturition may appear to be abnormally long and this, along with the common knowledge that heifers often require assistance, might make it more likely for someone to decide that a heifer needs assistance.

If an automated system was successfully developed, it may not improve the way that cows are managed at parturition. Although the aim is to develop an aid in addition to normal monitoring of cows around parturition, it may replace or reduce the frequency of observations by the farm workers. Although accelerometers could potentially be used to monitor some behavioural states in dairy cows, these behaviours alone are unlikely to give as detailed an assessment of a cow’s state as a visual observation by an experienced stockperson.

It would be extremely difficult to develop an automated system with the observational abilities of a trained stockperson. Therefore, it may be more productive and beneficial to dairy cows if research effort is focussed elsewhere. Prevention or reduction of calving problems should be prioritised and the costs of calving difficulties emphasised to encourage changes to be made to how dairy cows are managed. It may take some time to reduce the prevalence of calving problems but research could be conducted to provide improved guidelines and training for farm staff on the signs of calving and when assistance may be required.

In conclusion, the changes observed in dairy cows before calving are highly variable between individuals and there is no universal rule that will determine when calving will happen or if there will be any problems. This means that even the most sophisticated technology will struggle to achieve better results than an experienced or well-trained stockperson.

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Appendix A: Missing data from Chapter 4

Calving observations. Columns show each hour of the 24-h observations of 20 cows. Green represents when cows were out of sight and red represents problems with videos.

Cow	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
4																								
13																								
30																								
47																								
51																								
53																								
80																								
85																								
101																								
122																								
130																								
136																								
156																								
187																								
189																								
191																								
205																								
207																								
216																								
248																								

Control observations. Columns show each hour of the 24-h observations of 20 cows. Green represents when cows were out of sight and red represents problems with videos.

Cow	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
4																								
13																								
30																								
47																								
51																								
53																								
80																								
85																								
101																								
122																								
130																								
136																								
156																								
187																								
189																								
191																								
205																								
207																								
216																								
248																								

Appendix B: Missing data from Chapter 5

Calving observations. Columns show each hour of the 12-h observations of cows and heifers that were either unassisted or assisted using a calving jack. Green cells represent when cows were out of sight.

Cow ID	Cow or heifer	Assisted?	1	2	3	4	5	6	7	8	9	10	11	12
100	Cow	No												
138	Cow	No												
157	Cow	No												
195	Cow	No												
236	Cow	No												
246	Cow	No												
7	Cow	Jack												
81	Cow	Jack												
92	Cow	Jack												
109	Cow	Jack												
154	Cow	Jack												
201	Cow	Jack												
177	Heifer	No												
233	Heifer	No												
257	Heifer	No												
305	Heifer	No												
314	Heifer	No												
320	Heifer	No												
98	Heifer	Jack												
208	Heifer	Jack												
215	Heifer	Jack												
294	Heifer	Jack												
297	Heifer	Jack												
298	Heifer	Jack												

Control observations. Columns show each hour of the 12-h observations of cows and heifers that were either unassisted or assisted using a calving jack. Green cells represent when cows were out of sight and red cells are when there were problems with the video equipment.

Cow ID	Cow or heifer	Assisted ?	1	2	3	4	5	6	7	8	9	10	11	12
100	Cow	No												
138	Cow	No												
157	Cow	No												
195	Cow	No												
236	Cow	No												
246	Cow	No												
7	Cow	Jack												
81	Cow	Jack												
92	Cow	Jack												
109	Cow	Jack												
154	Cow	Jack												
201	Cow	Jack												
177	Heifer	No												
233	Heifer	No												
257	Heifer	No												
305	Heifer	No												
314	Heifer	No												
320	Heifer	No												
98	Heifer	Jack												
208	Heifer	Jack												
215	Heifer	Jack												
294	Heifer	Jack												
297	Heifer	Jack												
298	Heifer	Jack												

Appendix C: Missing data from Chapter 6

Calving observations. Colours show gaps in behaviour (green is when cows were out of sight and red represents problems with videos) and X shows missing accelerometer data.

Cow	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
4	X	X	X	X	X	X																		
13	X	X	X	X	X	X	X																	
30	X	X	X																					
47																						X	X	X
51																								
53	X	X	X	X																				
80	X	X	X	X																				
85																				X	X	X	X	X
101	X	X	X	X																				X
122																								
130	X																							
136	X	X	X	X	X																			
156																								
187																								
189																								
191																								
205																								
207	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
216	X																				X	X	X	X
248																								

Control observations. Colours show gaps in behaviour (green is when cows were out of sight and red represents problems with videos) and X shows missing accelerometer data.

Cow	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
4	X	X	X	X	X	X	X																	
13	X	X	X	X	X	X	X	X	X															
30	X																							
47																					X	X	X	X
51																								
53	X	X	X	X	X	X	X	X	X	X	X	X	X											
80																								
85																								
101	X	X	X	X																				
122																								
130																								
136	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
156																								
187	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
189																								
191	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
205																								
207																								
216	X	X	X	X																				
248																								